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THE RAPE OF THE EARTH:
A WORLD SURVEY OF SOIL EROSION

THE RAPE OF THE EARTH

A World Survey of Soil Erosion

by

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Soil Erosion

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To gain control over the soil is the greatest achievement of which mankind is capable. The organization of civilized societies is founded upon the measures taken to wrest control of the soil from wild Nature, and not until complete control has passed into human hands can a stable superstructure of what we call civilization be erected on the land. The great advances in science and particularly in transport during the last hundred years have enabled civilized men to penetrate into every corner of the earth, carrying with them the mixed blessings and curses of civilization. They have planted the tree of European civilization over four continents, and in some places it has appeared to thrive. But scarcely anywhere has it taken firm root in the soil, for European men, despite their skill and power over Nature, have learnt only how to cultivate European soils in a European climate. Modern civilization, outside Europe, is more like a plant that will burst its bud and blossom for a short time in a vase than like a tree that will grow indefinitely with its roots in fertile soil. All seems well with the plant while it continues to blossom; but the flower soon fades and the plant on which it blossomed dies.

All seemed well with civilization in the century of expansion that followed the Industrial Revolution. It was a beneficent growth destined to take possession of the world, and to receive a new lease of life in the countries of the New World as it grew old and declined in Europe. But for some years before the Great War, faint and usually unnoticed signs were appearing that the early promises of the new countries were not to be fulfilled. The economic depression of the late nineteen-twenties brought matters to a head. The depression made the peoples of the world take stock of their position. They felt that the structure of civilization was tottering, and those that lived on the ground floor, near to the earth, began to investigate the stability of the foundations in the soil. Those in the upper stories, devoted to industry, politics, sciences and nearer to the light and sun, were fully occupied in propping up their tottering dwelling places and gave no thought to the foundations, without which all their efforts would be vain. Only within the last few years has some of the shakiness in the upper stories been traced to the crumbling foundations.

For, as the result solely of human mismanagement, the soils upon which men have attempted to found new civilizations are disappearing, washed away by water and blown away by wind. To-day, destruction of the earth's thin living cover is proceeding at a rate and on a scale unparalleled in history, and when that thin cover—the soil—is gone, the fertile regions where it formerly lay will be uninhabitable deserts. Already, indeed, probably nearly a million square miles of new desert have been formed, a far larger area is approaching desert conditions and throughout the New World erosion is taking its relentless toll of soil fertility with incredible and ever increasing speed. Science produces new aids to agriculture—new machines that do the work of a score of men, new crop varieties that thrive in climates formerly considered too harsh for agriculture, new fertilizers that double and treble yields—yet taken the world over the average output per unit area of land is falling. There is a limit to the extent to which applied science can temporarily force up soil productivity, but there is no limit except zero to the extent to which erosion can permanently reduce it. A nation cannot survive in a desert, nor enjoy more than a hollow and short-

lived prosperity if it exists by consuming its soil. That is what all the new lands of promise have been doing for the last hundred years, though few as yet realize the full consequences of their past actions or that soil erosion is altering the course of world history more radically than any war or revolution. Erosion is humbling mighty nations, re-shaping their domestic and external policies and once and for all it has barred the way to the El Dorado that a few years ago seemed almost within reach.

Erosion in Nature is a beneficent process without which the world would have died long ago. The same process, accelerated by human mismanagement, has become one of the most vicious and destructive forces that have ever been released by man. What is usually known as 'geological erosion' or 'denudation' is a universal phenomenon which through thousands of years has carved the earth into its present shape. Denudation is an early and important process in soil formation, whereby the original rock material is continuously broken down and sorted out by wind and water until it becomes suitable for colonization by plants. Plants, by the binding effects of their roots, by the protection they afford against rain and wind and by the fertility they impart to the soil, bring denudation almost to a standstill. Everybody must have compared the rugged and irregular shape of bare mountain peaks where denudation is still active with the smooth and harmonious curves of slopes that have long been protected by a mantle of vegetation. Nevertheless, some slight denudation is always occurring. As each superficial film of plant-covered soil becomes exhausted it is removed by rain or wind, to be deposited mainly in the rivers and sea, and a corresponding thin layer of new soil forms by slow weathering of the underlying rock. The earth is continuously discarding its old, worn-out skin and renewing its living sheath of soil from the dead rock beneath. In this way an equilibrium is reached between denudation and soil formation so that, unless the equilibrium is disturbed, a mature soil preserves a more or less constant depth and character indefinitely. The depth is sometimes only a few inches, occasionally several feet, but within it lies the whole capacity of the earth to produce life. Below that thin layer comprising the delicate organism known as soil is a planet as lifeless as the moon.

The equilibrium between denudation and soil formation is easily disturbed by the activities of man. Cultivation, deforestation or the destruction of the natural vegetation by grazing or other means, unless carried out according to certain immutable conditions imposed by each region, may so accelerate denudation that soil, which would normally be washed or blown away in a century, disappears within a year or even within a day. But no human ingenuity can accelerate the soil-renewing process from lifeless rock to an extent at all comparable to the acceleration of denudation. This man-accelerated denudation is what is now known as soil erosion. It is the almost inevitable result of reducing below a certain limit the natural fertility of the soil—of man betraying his most sacred trust when he assumes dominion over the land.

Man-induced soil erosion is taking place to-day in almost every country inhabited by civilized man, except north-western Europe. It is a disease to which any civilization founded on the European model seems liable when it attempts to grow outside Europe. Scarcely any climate or environment is immune from erosion, but it is most virulent in the semi-arid continental grasslands—the steppes, prairies and velds of North and South America, Australia, South Africa and Russia which offer the greatest promise as future homes of civilization. It is also the gravest danger threatening the security of the white man and the well-being of the coloured man in the tropical and sub-tropical lands of Africa and India. Until quite recently erosion was regarded as a matter of merely local concern, ruining a few fields and farmsteads here and there, and compelling the occupiers to abandon their homes and move on to new land, but it is now recognized as a contagious disease spreading destruction far and wide irrespective of private, county, state or national boundaries. Like other contagious diseases, erosion is most easily checked in its early stages; when it has advanced to the stage when it threatens the entire social structure, its control is extremely difficult. In the main, unimportant individuals have started erosion and been crushed by it, until the cumulative losses in property and widespread suffering and want have brought governments and nations, with their immense powers for good or evil, into the fray.

In the United States, the problem of erosion has become a dominant factor in national life; in South Africa, according to General J. C. Smuts, 'erosion is the biggest problem confronting the country, bigger than any politics.' In these two countries erosion has already assumed the proportions of a national disaster of the first magnitude, and has sapped their life blood to such a degree that only a tremendous and single-minded effort from a united nation can prevent a further rapid and irreparable decline. Fortunately, there are signs that the effort will be made in time. Elsewhere, the same destructive processes are at work, but owing to less intense exploitation in the past, they have not advanced so far as in the United States and South Africa. Nevertheless, governments, warned by the example of the United States in particular, are everywhere being compelled to take note of erosion, and when government stirs it means that the question involved is no longer the concern of one section, but of the whole of the community.

That the ultimate consequence of unchecked soil erosion, when it sweeps over whole countries as it is doing to-day, must be national extinction is obvious, for whatever other essential raw material a nation may dispense with, it cannot exist without fertile soil. Nor is extinction of a nation by erosion merely a hypothetical occurrence that may occur at some future date; it has occurred several times in the past. Erosion has, indeed, been one of the most potent factors causing the downfall of former civilizations and empires whose ruined cities now lie amid barren wastes that once were the world's most fertile lands. The deserts of North China, Persia, Mesopotamia and North Africa tell the same story of the gradual exhaustion of the soil as the increasing demands made upon it by expanding civilization exceeded its recuperative powers. Soil erosion, then as now, followed soil exhaustion. The early home of Chinese civilization in the north-west loessial region now resembles a huge battlefield scarred by forces far more destructive than any modern engines of war. The sculpturing of that fantastic landscape is the greatest work of Chinese civilization. Over vast areas the once deep and fertile soil has gone completely, and as it was washed away it tore gaping chasms, sometimes hundreds of feet wide and deep, through the underlying loess and deposited the

eroded material on the valley plains and in the rivers and sea. The Yellow River and the Yellow Sea are aptly named, for they are coloured with the yellow subsoil that still pours into them from the now barren loessial hinterland. Hundreds of miles from the eroding region, and for hundreds of miles along its course, the bed of the Yellow River is raised higher and higher above the surrounding country by the continual deposition of eroded soil, the headwaters, no longer absorbed by a porous soil, tear down the hillsides in increasing torrents, and the most disastrous floods in the world, which were once regarded as visitations from Heaven, are now normal and expected occurrences. The Yellow River transports an annual load of 2,500 million tons of soil. There are other rapidly eroding regions and great muddy rivers in China, but the gutted North-West and the Yellow River are the outstanding and eternal symbols of the mortality of civilization.

So in Mesopotamia, the River Tigris which once irrigated and enriched the empire of Babylon and Assyria now flows menacingly on a raised bed of eroded soil brought down from the hills when the plainsmen, seeking more water for their irrigated crops and more land to replace their exhausted soils, cut down the hill forests and were rewarded with uncontrollable floods that overwhelmed their fields and swept away their irrigation works, those great feats of engineering that assured man's passing supremacy over the soil.

On the desert fringes of the Persian and Carthaginian empires, soil exhaustion, crop failures and land abandonment allowed the desert sands to encroach relentlessly. The peoples, weakened at the source of their strength, fell a prey to human conquerors, themselves doomed to be overwhelmed by the drifting sands that now cover the Persian fields where Darius ruled, and the North African plains where Hannibal defended the rich lands of Carthage against the Romans.

But as the soils upon which these ancient civilizations were founded were being washed away or covered over with sand and mud, other civilizations possessing new knowledge and powers were growing up along the eastern and northern shores of the Mediterranean. The might of Greece and Rome had its origin in the mastery of the art of continuous cultivation on forest land

—a notable advance on the shifting cultivation (still widely practised by primitive communities) whereby the forest re-occupied the land after a few years and compelled the cultivators to adopt, at best, a nomadic tribal existence. Continuous cultivation of forest soils enabled permanent, organized communities to develop in a more favourable environment and to attain greater heights than the arid environment where civilization could only exist by irrigation. Mankind, however, never completely masters an art. Shifting cultivation, although it kept men as unimportant servants of wild Nature, maintained soil fertility indefinitely, since the forest drove the cultivator out and re-assumed its beneficent control as soon as any sign of soil exhaustion appeared. Continuous cultivation meant continuous depletion of the soil and always more deforestation to secure new land for the rapidly growing community and to replace worn-out soils. The soil, it is true, was recompensed to some extent by manuring and careful cultivation, but Nemesis could not be delayed indefinitely. The decline of the Roman Empire is a story of deforestation, soil exhaustion and erosion. Judea, likewise, was overcome by erosion. From Spain to Palestine there are no forests left on the Mediterranean littoral, the region is pronouncedly arid instead of having the mild humid character of forest-clad land, and most of its former bounteously rich top-soil is lying at the bottom of the sea. No people, however great and powerful in arms, could maintain its virility and dominance under the conditions that must have prevailed 1,500 years ago in the Mediterranean, and no dictator except Nature can restore the conditions that might allow another world power to arise there. That the Mediterranean countries have not suffered complete annihilation like the earlier empires bordering the deserts is due to the comparative rapidity with which new soil forms from the rock beneath. But soil formation has not kept pace with soil erosion.

In Central America, Colombia, Ceylon and other tropical regions the ruins of bygone civilizations, that struggled for a time to cultivate the tropical forests, have been unearthed. Those civilizations were exterminated completely when men could no longer hold their own on the soil. They succumbed without having contributed anything permanent to the ad-

vancement of mankind. When the forests were destroyed, no human power could control the destructive force of the torrential rains that swept the unprotected soils from the hills and flooded the plains, and to-day the forest again rules supreme, showing scarcely a trace of the overlordship once precariously held by man.

One after another, the great empires and civilizations of the past have been swept out of existence by soil erosion. Modern civilization in its birthplace in Western Europe, although subjected to many perilous stresses, seems immune from the danger of slow disintegration from soil erosion. It is dangerous to forecast the future from present conditions, but there are indications that Western Europe may already have passed its zenith while its soils remain the most productive and the most stable under cultivation in the world. The system of continuous cultivation of forest soils, evolved around the Mediterranean, has been gradually perfected in the colder and moister regions of the temperate deciduous and coniferous forest zones. Elsewhere, either in its original or in modified forms, it has proven almost always unsuitable as a basis of civilization, and sometimes immediately disastrous, for no sooner has European civilization established itself in a new country than soil erosion, the invariable destroyer of past civilizations, has set in.

The soils of Western Europe have not eroded in spite of being subjected to the most intensive cultivation in history because the system of cultivation evolved in Europe in the course of centuries has, *under European conditions*, enormously increased soil fertility—to such an extent that to-day the agricultural production of even such a small and industrial country as Britain equals in value that of all Canada. It has been argued that the European climate, with its absence of violent storms or excessive droughts, is particularly inconducive to erosion, but it would be more correct to say that Europe owes its immunity from erosion to the adaptation of its agriculture to its climate. The countryside has been desecrated and scarred with ugliness in many places, but the one inviolable condition on which man holds the lease of land from Nature—that soil fertility be preserved—has in the main been respected. The European farmer has regarded land as an inheritance to be

handed on to the next generation in at least as good a condition as when he received it. His attitude has not been born of altruism or necessarily of an innate pride in his work, but is attributable to the character of the natural forest soils which were originally unsuited for intensive agriculture and yielded the occupier a profit proportionate to the agricultural improvements effected in them.

The circumstances in which the New World has been opened up and colonized have been entirely different. With few exceptions, profit and wealth have been most easily won by exploiting and exhausting the virgin soils. In particular, grassland soils required merely a superficial cultivation to convert them immediately into almost ideal arable soils, rich in plant food, perfect in tilth, and apparently incapable of further improvement. Or they afforded rich and extensive pastures without having to be touched at all. The occupier of land was, moreover, a member of an embryonic community in which few restrictions were placed, or seemed necessary, on the use to which the land was put, while the insatiable demands of the Old World and the progress of agricultural science and machinery offered immense profits and further opportunities for exploitation to the man who cashed his soil fertility for labour-saving and yield-increasing devices. Over forty million acres of new land in the United States were brought under the plough during the war and immediate post-war period. They were exploited to the utmost to secure the high profits obtainable, and afterwards they were exhausted with no hope of improvement when debts, tariffs and nationalism barred their produce from oversea markets and ruined the occupiers. To-day much of those forty million acres has been eroded beyond repair or has become 'sub-marginal' land to be left for time and Nature to restore to fertility.

Examples could be multiplied indefinitely to show how in every part of the world circumstances beyond human control have compelled men to exploit their newly acquired dominions beyond the limit of safety. In almost every instance where the limit has been passed, soil erosion has started, slowly and inconspicuously at first but gathering momentum with ever increasing speed and becoming more difficult to check as its destructiveness spreads. Were soil erosion an occasional isolated

phenomenon confined to a few mismanaged farms, it could easily be dealt with, by changing the management or converting the managers of the farms to other ways. When it threatens a whole country with ultimate extinction, it can only be checked by changing fundamentally the country's management and the way of life of its people. When erosion becomes a national problem (and there are but few regions where it is not one now) it affects all classes and interests adversely, causes a progressive lowering of the general standard of living, and introduces into the community a feeling of insecurity that is inexplicable to those who see only outward signs of prosperity and are blind to the fact that the only sure foundation upon which a superstructure of civilization can be built is a stable soil. The civilizations of the New World, grown with unparalleled rapidity from European seed and nurtured largely on the political, economic and social traditions gradually evolved over a thousand years in Europe, are proving entirely incompatible with their natural environments.

For erosion is the modern symptom of maladjustment between human society and its environment. It is a warning that Nature is in full revolt against the sudden incursion of an exotic civilization into her ordered domains. Men are permitted to dominate Nature on precisely the same condition as trees and plants, namely on condition that they improve the soil and leave it a little better for their posterity than they found it. Agriculture in Europe, whatever its other weaknesses, has been, and perhaps still is, a practice tending on the whole to increase soil fertility. When adopted and adapted elsewhere it has resulted, almost invariably, in a catastrophic decrease in fertility. The illusion that fertility can always be restored by applying some of the huge amounts of artificial fertilizers now available has been shattered by the recognition that fertility is not merely a matter of plant-food supply (for even exhausted soils usually contain ample reserves of plant food), but is also closely connected with soil *stability*. An exhausted soil is an unstable soil; Nature has no further use for it and removes it bodily. The process is the same as denudation, but whereas under normal conditions a fraction of an inch of soil may become exhausted and be removed in a century, under human control the

entire depth of soil may become exhausted and be eroded in a few years.

Differences in the climates of the Old and New Worlds have undoubtedly greatly influenced the onset and spread of erosion, but climate is never (or only very seldom) the cause of erosion. To-day the most actively eroding regions are the semi-arid continental grasslands and the tropics, but erosion has only become a serious factor in their existence during the last few decades; for thousands of years before, these regions had preserved a perfect equilibrium between denudation and soil formation. It is a humbling thought that modern men, with their immense knowledge and capabilities, have been defeated by grass, whereas their ancestors succeeded in the more difficult task of subduing the forest. But they took a thousand years or more over the job; their modern descendants have acted as though, with their machines, they could conquer the grasslands in a century.

Leaving aside for the moment the question of how present agricultural systems and methods of land utilization have produced such disastrous consequences, we may enquire why these malpractices, which seem to threaten the whole future of the human race, should have been adopted and have become so prevalent in the newer countries. In the first place, the general principles and methods of land management that had been found eminently suitable for European conditions were the only ones fully understood by the colonizing peoples. Thereafter, the necessary modifications introduced in different countries into land-management practices were dictated not so much by natural environmental factors as by external economic circumstances, particularly those created by the rapidly developing opportunities for international commerce throughout the world. Thus the development of land in new countries has not been a gradual evolutionary process dependent upon local conditions, but part of a sudden and explosive surge of immense and uncoordinated human power into unprepared territory.

While the present world-wide despoliation of the earth and irreparable soil erosion may be ascribed to a general maladjustment of land-utilization practices to the natural environment, the reason for that maladjustment is to be found as much in distant countries as on the sites of erosion. Men have not been

ruining their newly gained inheritance for amusement, or from some innate destructive instinct or even from thoughtlessness, but because under the circumstances and with the knowledge they possessed they could do little else. The immediate needs of the rapidly increasing European population in the nineteenth century necessitated an unrestrainable exploitation of new virgin lands without regard to ultimate consequences, which were in any case unforeseeable. Europe took everything that the new countries could send, and the latter willingly bartered their life blood for the amenities of civilization and the opportunities offered for national and personal advancement. Nineteenth-century economy, especially within the British Empire, was based on the mutual exchange of agricultural and industrial produce. That the New World was being robbed of its soil and was being paid in coin that brought no recompense to the land never entered the heads of either partner to a bargain which seemed, and at the time was, natural, sensible, and highly satisfactory to all concerned. The price that has been, and still must be, paid in soil and in the social security, prosperity, health, contentment and aesthetic values that go with it, for the outward show of civilization and wealth, is incalculable.

The successive stages of soil erosion, and the extent to which a region or country is affected at each stage, vary greatly. The onset of erosion is usually insidious, its early harmful consequences are ignored or attributed to the passing vagaries of season or climate, and not until it has become epidemic over a large area is the need realized for adequate control measures. The difficulties of control increase in proportion to the amount of erosion in geometrical rather than arithmetical progression.

The earliest stage of erosion is a loss of fertility. Whatever the cause of the loss, the result is invariably a corresponding loss in soil *stability*; the soil is deprived not only of its productive power, but also of its capacity for remaining in place. Fertility is a term that should be applied to the soil and vegetation together, for the soil derives its capacity for producing life from the vegetation, as much as plants derive their capacity for growth from the soil. Apart from the indispensable plant-food elements and humus returned to the soil by the dead vegetation, the *living* vegetation protects the soil in many subtle ways from the

erosive effects of wind and rain. Any loss of plant food and humus incurred in cropping or cultivating soil may be made good by fertilizers and manures, but the loss of soil protection incurred by destroying or changing the natural vegetation can only be recompensed by a cultural system that produces the same or equivalent physical effects on the soil as did the natural vegetation. Thus a deterioration in the physical properties and fertility of soil is the invariable precursor of actual erosion.

The most significant physical deterioration resulting from cultivation is a reduction in the porosity and cohesion of the soil. Rainwater, that was formerly absorbed by the soil, then runs off the surface, carrying soil with it, and 'sheet erosion' begins. This is usually unnoticed, as only a fraction of an inch of soil is removed in a season, but the trouble is already well advanced, for the next layer of soil exposed at the surface is less absorbent than was the eroded layer, the amount of run-off water increases further, and the rate of erosion is steadily accelerated. In a very short time, the run-off collects in rivulets where its erosive and transporting powers are enormously increased. The rivulets become gullies and the gullies coalesce to become chasms, penetrating through the soil into the barren subsoil. Stuart Chase in *Rich Land, Poor Land* describes how a chasm, 3,000 acres in extent and 200 feet deep, in Georgia, U.S.A., started to grow forty years ago from water dripping unheeded off a barn roof and forming a little rill that became a rivulet that became a torrent that tore away the soil and subsoil over an ever-widening area and flung whole farmsteads into the gaping wound. Other chasms and gullies, tributaries of this greatest, cover 40,000 acres in the neighbourhood. Chase likened the scenery to the Yellowstone canyon which Nature fashioned in millions of years. Men have worked quicker; only half a century has been needed to fashion the new canyon of Georgia.

Gullies are among the more spectacular results of erosion; without them the far more insidious and widely destructive processes of sheet erosion might pass unnoticed for much longer. Sheet erosion is like a wasting disease that affects the whole body but exhibits no serious outward symptoms until it is so far advanced that only a complicated treatment can effect an uncertain cure. The ugly scars on the landscape produced by gully

erosion are often the first warning taken that something serious has been happening for several years over a much greater area of still unscarred land. For gully erosion which, if unchecked, can cause incalculable havoc, is the direct consequence of, and can only be controlled by preventing, sheet erosion.

When gully formation has begun, the land has already lost, apart from soil material, much of the most important element in soil fertility and stability—the water-holding capacity of the soil. The capacity to absorb and retain water is a very characteristic property of a mature, fertile soil. It is scarcely, if at all, developed in bare weathered rock formations (except heavy clays) that have never carried vegetation and contain no humus. Normally the water-holding capacity of soil is confined mainly to a few inches on the surface where fresh humus, formed from decaying plant and animalremains,accumulates. Sheet erosion,by removing the most absorbent layers, not only greatly increases the amount of run-off water which is the principal eroding agent, but equally decreases the value and usefulness of the rainfall. In semi-arid countries, where every drop of rain is needed to maintain some life, this consequence of erosion is far more serious than the actual loss of soil. Therecent spells of drought years in North America, South Africa and Australia would not have been so devastating fifty years ago, as much more of the rain would have been held by the absorbent soil and utilized by the crops. To-day an abnormally high rainfall is required to produce the same results as an average rainfall would have produced then; but to-day a high rainfall also tends to wash away more of the remaining soil than a low one. Where erosion has occurred, rain is no longer an unmixed blessing. In many parts of these countries drought has come to stay, regardless of the weather.

What happens, and does not happen, when as a consequence of a little sheet erosion, a part of the annual rainfall runs off the surface? In countries with a strictly limited water supply, the total natural productivity of the land is immediately and permanently reduced, since the maximum productivity is fixed by the amount of rain retained by the soil rather than by the total rainfall. As run-off is accompanied by erosion, the water-holding capacity of the soil is further reduced, the proportion of run-off to total rainfall increases, and productivity decreases,

progressively. At the same time the underground water supply, normally fed by water filtering slowly through the soil, diminishes. Wells and springs dry up or only flow intermittently, town water supplies are endangered and a progressive desiccation of the whole country is observed. It is popularly believed in South Africa that the average rainfall—at best, barely sufficient for the existing population—is decreasing, because droughts appear to be more frequent and severe. The country is definitely more arid than it was half a century ago, but the cause lies more in the loss of the absorbent soil covering than in a falling rainfall, and the normal humidity, productivity, and capacity to support a growing population can only be restored by renovating the soil. Soil erosion strikes directly at the very roots of South Africa's existence and is the gravest and most urgent problem confronting the country at the present time.

The run-off water is, however, water, and it would not appear to be beyond the capacity of man to store or utilize it for productive purposes before it is lost in the sea. In actual fact, run-off water is ordinarily worse than useless, and human ingenuity is fully occupied in preventing it from completing the chaos started by sheet erosion rather than in utilizing it. The drainage system of a river basin (which forms a natural unit of country in questions of erosion control), has been shown to be so related to the topography, soils, vegetation and climate of the basin that it is perfectly adapted to deal with the normal discharge of water into the main river. Widespread floods are unusual in regions undisturbed by man. Even the immense volumes of water released by the spring thawing of snow on mountains are sufficiently retained by the porous litter and soils of undisturbed forests to prevent an excessive discharge into the rivers. But when man cuts down the mountain forests and destroys the sponge-like properties of the forest floor, flood, after a thaw or heavy rain, is almost inevitable, as the forest was an essential part of the natural drainage system. Deforestation, with or without perceptible soil erosion, of mountain watersheds is, indeed, the commonest cause of recurrent floods the world over. The most costly works of mountain flood control are hopelessly inefficient in comparison with actual forest.

Similarly when natural grassland, on even the gentlest slope,

is mismanaged by injudicious cultivation, say, or by overgrazing, soil fertility is reduced, erosion commences, and soon the amount of run-off water begins to rise. It is not unusual for the run-off from a cultivated prairie to increase in a few years from a normal 1–2 per cent to 10–20 per cent of the annual rainfall—i.e. ten times. When the whole or the greater part of a natural drainage basin is thus mismanaged, the result is that enormously excessive quantities of water are discharged into the rivers during the wet, and abnormally small quantities during the dry seasons. Hence rivers associated with eroded regions are characterized by marked irregularity of flow, periods of flood being followed by periods of very low water, which (apart from flood damage) greatly reduces their utility for navigation, town water supplies, hydro-electric power, irrigation, etc. It is obvious that the loss and damage caused in this way by erosion are not confined to the eroded regions but may extend over the whole length and breadth of a great river basin like that of the Mississippi—which in many places is now more a menace than a blessing to the country through which it passes. There can be no doubt that the increasing frequency and catastrophic nature of the Mississippi floods are largely due to soil erosion in both neighbouring and distant regions.

In recent years recurrent floods have caused havoc in the irrigated valley of the Wasatch Mountains in Utah. Since early settlement the mountain slopes above the valleys have been in great demand for grazing purposes and in many places deforestation and overstocking have practically destroyed the natural vegetation, and advanced erosion and gully formation have occurred. When rain falls on the mountain slopes, it is as though it fell on a bare roof, many square miles in area. The rain collects in the gutters formed by the gullies and pours in a sudden discharge into the valley, sweeping everything before it. Alluvial deposits in the valley tell the story of floods for the last fifty thousand years; there have been none to equal the recent floods for at least twenty thousand years.

The task of restricting the damage done by, and of utilizing productively, the excessive and often priceless run-off water is of

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2. Drakensberg Mountains, South Africa.

the utmost difficulty, owing to the fact that the water carries a load of soil. When soil is washed from a field, with its irreplaceable content of vitality and fertility, it might be thought that the damage, as far as the soil was concerned, was completed, but it has only begun. The water breaks down the transported soil crumbs into their constituent particles of sand, silt and clay thereby destroying most of the characteristic soil properties and fertility, so that even when the eroded particles are re-deposited on cultivable land, they have lost much of their former productive capacity. The transported particles themselves have a powerful erosive effect, tearing away more soil as they pass over the land, and widening and deepening gullies until the run-off water is loaded to full capacity. The capacity of running water to hold soil in suspension depends upon the velocity of flow and the size of the suspended particles; doubling the velocity increases the carrying capacity no less than 64 times, and the size of particle transportable 128 times. Thus gullies, by continually eating into the land and thereby increasing the angle of slope and the velocity of run-off water, enormously accelerate erosion. They grow with amazing rapidity and form rushing, muddy torrents after every rain. The torrents find their way into the tributary rivers and natural drainage channels where the inclination is usually less and, as the velocity of flow decreases, the coarser suspended particles are deposited on the river beds. The river beds rise, and continue to rise with each deposition of sand, the excess of water pours over the country in uncontrolled flood. In time, the normal drainage channels become clogged and new channels form, but *without regard to the natural drainage requirements of the region.* The result may be heavy flooding and waterlogging in some parts, overdrainage in others, further extensive erosion and landslides—in short the dislocation of the productive mechanism, whether natural or man-controlled, of the entire region.

Besides a tendency to flood and irregularity of flow, a further characteristic of rivers associated with eroding regions is muddi-

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3. Results of floods of 1930 at the mouth of Parrish Canyon in Centerville, Davis County, Utah. Compare damage from protected and unprotected canyons. See page 32.

ness. The waters are saturated with fine silt and clay that fall out of suspension only very slowly and at low river velocities, and give rise to conditions inimical to fish life. Fish are disappearing, or have disappeared, from many rivers which once ran clear but now are turbid with soil that perhaps has been transported from hundreds of miles away.

When the waters reach a main river, the danger of flood is multiplied by the confluence of many overladen tributary streams, and the damage inflicted by flood is also likely to be greater, since dense human settlements tend to concentrate near the banks of main rivers. A main river generally flows more slowly than its tributaries, causing the deposition of some of the fine mud that remained in suspension in the more rapidly flowing streams. The river bed rises and the flood menace increases in magnitude and frequency. Cities threatened with inundation have to be protected by building high banks, sometimes towering above the roofs of the houses, to confine the river, agricultural land is intentionally flooded to relieve the pressure on more densely populated districts and huge dams are constructed in an attempt to regulate the flow of turbulent water. But experience has shown that the engineer alone cannot permanently control a great muddy river continually being supplied with millions of tons of eroded soil. The artificial banks must be raised, ultimately to breaking point, as the river bed rises, the dams built to trap the water trap also silt and clay which choke the reservoirs behind the dams, and the last state of the river is far worse than the first. There is nothing on land more beneficent to organized life than an orderly river, or more perpetually menacing than a river run amok.

It would, indeed, make things much easier for mankind if all the soil of which men rob their fields were lost for ever in the depths of the ocean. Siltation—the deposition of eroded soil on river beds—is among the worst and most intractable consequences of erosion. It may take several centuries for siltation to put a river out of control, but other troubles, beside the incessant danger of flood, arise long before the uncontrollable stage is reached. River navigation, which often constitutes an essential link in a country's chain of commerce, is seriously impaired or destroyed by siltation; storage reservoirs, whether

constructed for flood control, irrigation, hydro-electric purposes or public water supplies, become silted up and useless with incredible rapidity, for the dam that blocks the reservoir stops the water flowing, and down comes all the suspended soil. In fact, almost every useful function that running water is expected to perform in an organized community is impaired by erosion and siltation, and every danger that it may threaten is brought nearer to realization.

The consequences of erosion by water may be summed up as the localized reduction of productive capacity due to direct losses of soil and (often still more serious) of soil moisture, and the general disorganization of whole regions resulting from the cumulative dislocation of the natural water régime. The various destructive processes react upon each other and gather accelerating momentum as they proceed. It is this fact which makes the present world-wide erosion a matter of the greatest import to humanity at large. There is danger in complacency continuing because the earth is still rich enough in capital resources, expressed as soil fertility, to support its human population for a long time to come. One day we may realize that the capital is exhausted and no more dividends will be paid. It is not so much the damage already done that matters as the final and inevitable disaster to civilization that will occur if the contagion is allowed to spread until it is uncontrollable. A war-scarred country can be restored to prosperity in a few years; a field stripped of its soil is finished, at least as far as providing for the living generation is concerned, but can continue to spread destruction over other land.

The processes of wind erosion are less complex than of water erosion. The predisposing conditions for wind erosion are (1) an absence of protective covering for the soil and a low fertility level, causing the soil to pulverize; (2) a dry period, as wet soil does not blow appreciably; and (3) a broad, flat or slightly undulating region across which wind and soil can move unhindered. Nature has arranged that where water cannot punish man for his ignorance and misdeeds, the wind can.

When a large open area has been consistently mismanaged and its fertility reduced below the safety point, wind erosion can produce chaos within a few days. The wind lifts the pulverized

soil bodily from the surface, the atmosphere is choked with sand and dust, men and animals are suffocated, standing crops are torn up in one place and buried in another, leaving the countryside as though a hurricane had passed. The great dust storms which have swept the American prairies in recent years and darkened the sky over the Atlantic cities and far out to sea, were not freaks of Nature; fifty years ago, stronger winds than accompanied these dust storms would have blown over the grass-covered prairies and left no trace of their passage.

Like water erosion, wind erosion may start comparatively harmlessly at a few vulnerable points, such as small bare patches of soil or the tops of hummocks, and spread until the patches coalesce. Soil lifted by wind is itself a powerful erosive force, destroying the vegetation through which it passes and tearing other soil particles from the surface. The focal points from which erosion starts tend to enlarge rapidly, and once soil drifting has taken hold of a plain, there is no telling where it will stop. Wind-borne, like water-borne, soil is disintegrated into its component parts, the heavy sand particles are first re-deposited on the land as dunes or drifts, the finer particles are carried further in a cloud of dust and only fall when the force of the wind is spent, perhaps thousands of miles from the source of erosion. The fine particles sometimes settle as a thin layer that cakes after rain to a veneer through which water does not easily penetrate. The next rain runs off the surface and the stage is set for water erosion to play its part.

Wind erosion, taking the world over, has not occurred so extensively as water erosion, largely because men prefer to make their homes in hilly, well-watered places rather than in arid plains, but where it has occurred its effects have been catastrophic. It has given the name of the Dust Bowl to an immense area in the Middle West of the United States; and Canada, Russia, Australia and South Africa all know its terrors.

Water and wind erosion radically upsets the delicate equilibrium existing between the life and the climate of a region. The attainment of this equilibrium under natural conditions is usually referred to as 'adjustment to environment', the study of which comprises the science of ecology. Erosion and erosion control are essentially problems relating to the maladjustment

of human communities to their environment, i.e. they are fundamental problems in human ecology. The attainment of any stable equilibrium in a country or region suffering from severe erosion is an impossibility for the simple reason that the environment to which mankind must adjust itself is continually changing for the worse. The two principal environmental factors—soil and climate—affecting human activity deteriorate; the soil disappears bodily, and the climate, even though meteorological records may indicate no appreciable change, tends in effect to become progressively more extreme. Light rains become useless, heavy rains destructive, normal winds have the effect of tornadoes. Man is the most adaptable of all creatures to different climates, but he cannot evolve a stable community organization capable of rapid re-adjustment to a continually deteriorating environment, and if he could, the result would scarcely conform to the conception of an advancing civilization. Cities may spring up like mushrooms, railways and roads may span a country, bank balances may multiply, but while the soil is deteriorating and disappearing the net movement is away from rather than towards a civilized state. The retrograde movement can only be reversed by reversing the process of soil destruction, that is, by adequate erosion control combined with constructive agricultural methods. For when anarchy breaks loose in Nature the involvement of mankind in the consequences cannot long be delayed.

The first practical measures that can be taken to check the progressive extension of erosion include the use of simple mechanical devices such as banks or terraces suitably located on eroding slopes, dams across gullies, windbreaks, etc. Their primary object is to reduce the velocity and therefore the erosive power of run-off water or wind. But these measures alone have a merely local effect and scarcely touch the fundamental cause of erosion which is faulty land utilization—perhaps the destruction of forests that regulate the headwaters of a great river, the cultivation of land which, however suitable it may be for crop production, cannot safely be brought under the plough, or unrestricted grazing. It has been abundantly proved that patchwork erosion control is only a temporary palliative; control, to be permanently effective, must embrace entire natural regions (as,

for example, a river catchment) and must seek at removing the cause rather than the consequences of erosion. For the ravages of erosion are not confined to the actively eroding area but spread in ever widening circles until every aspect of the region's, or even the nation's, life is affected.

In badly eroded regions—and these are the ones where the causative malpractices are most firmly established—erosion control may mean the complete re-organization of land utilization either by voluntary agreement among land occupiers or under a regional plan enforced by a central authority. Where several regions in one political unit are affected (as in the United States) a national plan of land utilization may be required to coordinate the separate regional plans. Where land-utilization practices are firmly established and have become the basis of a country's economy, the adoption of a new land-utilization programme conforming to the limits imposed by the natural environment, may well involve a social and political revolution. Therein lies the supreme difficulty of applying effective erosion control. We now know fairly precisely what agricultural, pastoral, forest and engineering principles must be adopted to stop the earth from rotting away beneath our feet, but we cannot, or dare not, apply them forthwith on a scale commensurate with the gravity of the situation.

Great changes will have to be made in the kinds and quantities of crops produced, exported and imported by different countries, internal and external trade relations and policies will be affected, and perhaps most significant of all, the conditions of land tenure and occupancy upon which the social structure of a civilized community is founded, will have to be re-defined. Erosion control, acknowledged in many rapidly developing countries as the most vital problem confronting them, means going back to the beginning and re-building human society in a frame whose shape is determined by the intrinsic nature of the soil and is independent of immediate economic or political considerations.

Soil erosion has made a knowledge of the underlying principle of human ecology—the art of living together with animals, insects, and plants—one of the most urgent needs of mankind, and particularly of those who can see clearly the consequences

of the uncontrolled or miscontrolled use of science for exploiting natural resources. If a new civilization is to rise in America, Africa, Russia or Australia, it must start from small beginnings after the most relentless struggle that men have ever waged with Nature—a struggle that will fuse disruptive influences in a common effort and for a time will release the nations from the Nemesis of self-destruction that seems imminent over Western Europe. The unprecedented land wastage now going on has set us, with our vast powers, a task that can profitably occupy the surplus human energy released for constructive or destructive purposes by the advance of science. Misapplied science has brought to the world's richest virgin lands a desolation compared with which the ravages of all the wars in history are negligible. New outlooks, new aims and new knowledge will be required before the earth is again fit to rear, after long travail, another civilization. The rise of a civilization has always been preceded by a victory over natural forces that at one time must have seemed well-nigh unattainable. The urge to constructive endeavour released by the imperative necessity for stopping erosion may be the foundation upon which a great superstructure of human achievement will ultimately be built. Without that urge, born of the almost universal destructive exploitation of natural resources, mankind would have vegetated indefinitely in the grassland regions and would never have learnt their immense potentialities under human control.

CHAPTER II

Europe and the Mediterranean

Deforestation in Mediterranean countries in Greek and Roman times. The modern problems. Bonifica integrale and the Apennine clays. Change from fertility to aridity in Cyprus. Erosion and the intensification of Turkish agriculture. The ruinous state of Palestine. Erosion not a major problem in northern and central Europe. Soviet Russia affected by sheet and gully erosion, wind erosion and the advance of the desert.

We have already shown how the empires of Babylon, Assyria, Persia and Carthage were destroyed by the advance of floods and deserts, caused by the increasing clearing of forests for agricultural land and for additional supplies of water for irrigation. There was serious and excessive deforestation in the Apennines in Roman times and even earlier in Greece, where the demands of Phoenician commerce aided the denudation. The early demands of the Etruscans on the forests of the Apennines were followed by those of the Romans, and the climate of the deforested mountains did not favour natural regrowth. Attention was then directed to the Alps, but deforestation in the Pyrenees and Alps does not appear to have become serious until the later Middle Ages. Deforestation in these mountains is stated to have been less a result of commercial exploitation than of the over-population of the valleys, with a consequent increased demand for cleared fields, pastures and fuel. Deforestation in France, particularly in the Pyrenees, has caused almost catastrophic erosion, and national attention has been aroused on the question of reforestation of the denuded slopes.

Consequently, at the present day, the Mediterranean countries are faced with the problem of erosion and flood control. Part of the vigorous land reclamation programme (bonifica

integrale) of the Italian Government is directed towards the problem of the proper utilization of the clays of the Apennine foothills; these clays cover about one-fifth of the country and their reclamation from their present degraded and eroded state presents a problem which is typically Italian. Reforestation is also being pushed forward energetically; the results will be of particular importance, as they may be useful to many other parts of the Mediterranean similarly affected. The usual reforestation methods of Northern Europe do not apply in the Mediterranean climate, and special systems are being developed.

Other examples of the damage caused by erosion in the Mediterranean region may be seen in Cyprus, Turkey and Palestine.

Authorities state that there are no indications that the climate of Cyprus has changed during the last 3,000 years. The change from fertility to aridity has been due entirely to deforestation. Those forest areas which have been more or less preserved for the past fifty years are showing much improved growth and a thin humus layer is forming on the soil. The need for preservation in other categories of forests is not fully recognized by the people; the natural vegetation has been seriously disturbed by unrestricted pasturing of sheep and goats, the latter being an important source of livelihood in the hills. The numbers of sheep and goats are now restricted more by deaths through starvation and disease than by flock and pasture management. Considerable areas have been denuded of natural vegetation by cutting of fuel, the demand for which becomes increasingly acute with the rise in population.

The exposed hills on steep slopes are very susceptible to erosion and the numerous streams and winter torrents rushing down from the mountain ranges during the rains remove enormous quantities of soil, which are either distributed over the plains as a thin layer of very erodible silt or carried out to sea. Forestry, dry stone walling or terracing, reduction of livestock (particularly goats), and prevention of fuel cutting are methods being used for control of soil loss and excessive run-off.

Turkey has suffered very severely from erosion in the past; all

the erstwhile ports on the southern side of Anatolia are now silted up; Tarsus, once visited by Cleopatra's fleet, is now an inland town ten miles from the sea. It is stated that the mouth of the Great Menderez River has advanced seawards at the rate of about half a mile per century within the last 1,900 years. The country still shows many examples of erosion, due partly to the torrential type of rainfall, deforestation and the cultivation of crops (maize, wheat, barley, tobacco, nuts, etc.) which do not provide adequate ground cover. In the reconstruction of agriculture now in progress, intensification of production will play a part, but the country is still in a position to avoid the errors made in other parts of the world and to develop recognized conservation measures.

The hill country of Palestine comprises some 60 per cent of the non-desert area of the country and could all be habitable and productive. It is in a ruinous state and many slopes with high rainfall are devoid of permanent vegetation and practically denuded of soil. The removal of the dangers due to carnivores and cattle thieves, previously safeguards of the remnants of the scrub vegetation, has led to further excessive grazing and the disappearance of the natural vegetation from great areas. The very completeness of the destruction encourages inaction, as to the average man it appears merely quixotic to start the long task of reclaiming a wilderness of stony slopes. Disastrous floods in 1933 and 1934 have attracted attention to the steep Tiberias slope above the western shore of the Sea of Galilee. The destruction of the scrub cover having recently been completed, each heavy rain brings down a flood from the limestone and a mud-flow from the basalt. Spectacular floods have also occurred in Syria. According to the Report of the Palestine Royal Commission (1937), 'the fact has to be faced that there are to-day no real forests in Palestine and that if there is one country in the world in which afforestation is desirable that country is Palestine.' There are only seventy-six square miles of scrub forest and plantations, out of some 6,250 square miles fit for cultivation or afforestation, and of the total land area of 10,400 square miles. Only a little over twelve square miles have been reforested since the Great War, but it is considered that at least 15½ square miles should be planted every year with 6,500,000

forest and carob trees, the fruit of the latter providing valuable forage.

In northern and central Europe erosion is not a major agricultural factor, for the reasons stated more fully elsewhere, namely, absence of a torrential type of rainfall and the development of a type of agriculture particularly adapted to the forest soils and to the conservation of fertility therein. None of the special conservation techniques developed for more erodible countries are used except in rare cases such as the terraces in the Rhine Valley, the basis of conservation generally being the maintenance of organic matter in the soil by devoting special care to crop rotation. It is not yet clear whether, under the strain of economic nationalism or of a sudden 'emergency', these rules might be relaxed, rotation allowed to become less efficient and cultivation carried up steep slopes.

Although there is little gully erosion in European cultivated lands, there is certainly sheet erosion, the gradual drift of soil material carried in suspension from higher parts of a field to the lower. It is occurring with varying degrees of rapidity in Great Britain, but the British agriculturist or farmer is not erosion-conscious to the same extent as the American, particularly as regards the rather difficult problem of diagnosing sheet erosion, the most insidious type of soil loss. A certain amount of erosion must have occurred when the Welsh hills were first cleared of their forests. Indications of former erosion can be seen in the irregular topography, the badly drained hillside swamps, the extreme paucity of soil in some places, the frequent occurrence on the surface of a compact, brown soil horizon characteristic of the subsoil developed under an earlier forest vegetation, and extensive deposits in the valleys of material resembling the surface horizon of forest soils. The better drained parts of the Welsh hills are now clothed with grass which has produced a special kind of hard granular structure in the compact surface soil. As a rule these soils are extremely resistant to erosion and may be safely ploughed up and down steep slopes under a heavy, annual rainfall. Had it not been for continued human intervention (the introduction of grazing) the Welsh hills would have reverted to forest, and a new loose and erodible horizon, protected by a mat of forest litter and humus, would gradually

have developed. Sheet erosion is going on at the present day, particularly on light soils and in the more hilly cultivated lands in the higher rainfall areas of Wales and Scotland. Eroded patches in sloping arable fields, best seen when the cereal crop is coming up, bald areas on poor-grade pastures with an insufficient sward cover, piles of eroded soil on roadways, sudden flooding of rivers and discoloration of the sea along the coast due to the silt brought down from the valleys, all these are symptoms for the diagnosis of erosion. Although the climatic conditions probably do not warrant the more extreme type of conservation practices, such methods as ploughing, cultivation and planting up and down slopes instead of on the contour should be discouraged on sloping land. A certain amount of strip cropping and rearrangement of hedgerows, dikes and fences may also have a beneficial effect. Probably more important is the effect of erosion control practices such as contour trenches or furrows on the run-off from hilly country, and thus upon the reduction of flood damage in the lower reaches of valleys such as the Severn and the Wye. The co-operation between authorities concerned with grassland improvement and afforestation would appear to be indicated, particularly in the selection of slopes and other areas for suitable treatment.

There are few reports of erosion on agricultural land in Northern and Central Europe, although this does not necessarily mean that at least sheet erosion is not going on. The position in the Alpine regions is now in a reasonable state of equilibrium, an appropriate balance having been struck between the use of forests for timber and fuel and of the Alpine pastures for grazing, without detriment to the valley communities below. Possibly more can yet be done to link up Alpine management with valley and plain flood control. As an example may be quoted the effect of the unregulated felling of forests in the Transylvanian Alps in Rumania upon the post-war levels and the frequency of floods of the River Tisza and its tributaries, flowing through the Plain of Hungary. Hungary is also affected by the problem of drifting sands, which are being fixed by appropriate afforestation as was done many years ago in the great dune area of the Atlantic coast of France, the Landes de Bordeaux. A recent article from Germany describes gully ero-

sion in certain moraine areas in the north and on the slopes of hilly country and sheet erosion in certain fine sand areas in Brandenburg, where the sand is often borne by the wind for considerable distances and the furrows of potato fields are often filled with sand. Serious erosion is also reported in Czechoslovakia, particularly in Rakovnik, Bohemia, and in the basin of the Borsavy River in the Carpathians.

The Soviet Union is affected by sheet and gully erosion on agricultural lands in Central Russia and Ukraine, wind erosion in the steppes and the threat of the desert in Soviet Central Asia.

One of the worst eroded areas, by reason of its steep and broken relief, is the south-western steppe region. A survey of Russian literature leaves the impression that erosion as an imminent menace is mainly confined to the intensively cultivated zone, although it is prevalent and increasing, in milder forms, over much larger regions, particularly in the 'chestnut-soil' areas which correspond ecologically with the short-grass country of North America. The Russians were among the first to plant shelterbelts[1] as windbreaks in the steppes, and great benefits in moisture conservation and crop growth are claimed for them (see Chapter XIII). The reclamation of desert areas is also an active line of research, the revegetation of the Central Asiatic deserts, which fortunately are characterized by a high water-table, being an essential part of the programme to prevent overgrazing by the stock introduced by the recently developed cattle industry (see Chapter XIII).

The more arid parts of the Soviet Union may possibly contain a number of plants of various types which will be of service to soil conservationists in other parts of the world. The expedition of H. L. Westover and C. R. Enlow, of the United States Department of Agriculture, to Soviet Central Asia to collect plants for use in the soil conservation programme in the more arid parts of the United States may be quoted as an example. It is probable that species would also be found which might be of great service in the arid regions of Australia, South Africa and

[1] The term 'shelterbelt' or 'windbreak' is used for rows of trees placed parallel and at intervals in more or less flat country to protect the intervening crop areas from high winds.

similar countries. The Soviet workers themselves are paving the way by making a comprehensive survey of the plant resources of the Union. There can be little doubt that animal husbandry will play an important part in the future development of Russian agriculture. The Soviet Government is alive to the value of the still largely unspoiled natural grasslands which cover some of the most fertile parts of the country.

CHAPTER III

North and South America

Erosion and the pioneer phase. Theodore Roosevelt. Conservation a prominent political and social question. Operations of the subdivisions of the U.S. Department of Agriculture. Collection of data from experiments. The regional problems. The North-east. TVA. Piedmont. Corn Belt. Great Plains States. Dust Bowl. The Western Range. South-western States and the Indian Reservations. California. The quality of the 'frontier days'. Soil drift in Canada. P.F.R.A. Forest resources. South America. The West Indies.

This attempt to discuss erosion and conservation in North America, a subject to which an enormous mass of literature in the form of books, pamphlets and scientific articles has already been devoted, must necessarily be sketchy. The erosion of the United States has been given great publicity, in an attempt to drive home the gravity of the situation and the disaster which would undoubtedly have followed if the excessive loss of soil by water and wind erosion had not been arrested. The results of this publicity can now be seen in the nation-wide programme of soil conservation inaugurated by the Department of Agriculture and other Federal and State organizations, actions which are to impress the advantages of adopting the technique of a conservation agriculture and similar practices upon the farmers and other users of the land and its vegetation, wherever they are exposed to the eroding action of wind and water.

The history of erosion in the United States is bound up with the pioneer phase in the nation's development, through the stages of deforestation for agricultural land, timber, fuel and potash in the east, the development of the monoculture system of agriculture for maize in the Corn Belt and cotton to the south,

overstocking and ploughing up of the natural grassland areas of the Great Plains, gross overstocking and maltreatment of the range country, overgrazing and over-cultivation on the Pacific coast, and deforestation in the Pacific north-west. Astronomical figures have been frequently given for the millions of tons of soil washed down the muddy Missouri, the Mississippi and the other great river systems of the continent, or blown all the way from Kansas, Oklahoma and other States in the Dust Bowl to the Atlantic seaboard. More striking, however, is the statement quoted by Raymond Swing that, at the present rate of soil and water depletion, in fifty years the fertile soil in America will be a fourth of what was present originally and that, 'in a hundred years at the same rate of depletion the American continent could turn into the Sahara of the Western Hemisphere.' Even if this staggering statement is only half true, and the American people have two centuries of life on their continent, the prospect is bad enough.

The idea of conservation, to save America from the consequence of its rapid exploitation, is not new, but, apart from spasmodic attempts by enlightened individuals, it was Theodore Roosevelt who first aroused the people to its nation-wide importance. During his presidency attention was given mainly to plans for conserving mineral, forest and water resources. The high prices of the war and post-war period, however, encouraged waste on an unprecedented scale, and it needed the financial depression, and a series of droughts and spectacular dust storms to rouse the nation again to the much increased gravity of the situation. During Franklin Roosevelt's presidency, conservation has become a political and social question of the first importance, a plank in both the Republican and the Democratic platforms.

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4 *a*. Dust storm, Southern Great Plains, U.S.A. See page 54.
4 *b*. Wind erosion of ancient alluvial sandy terrace land on the Lower Don, U.S.S.R. As a result of excessive grazing and ploughing the sandy soil of the southern black-soil type was eroded to a depth of 1½ to 4½ feet. The illustration shows small knolls of accumulated sand bound by the psammophyte, *Elymus giganteus*, and the remains of the former soil. See page 45.

Most of the research and general conservation operations dealing with soil and vegetation in the United States are under the control of the Department of Agriculture, which is divided into some twenty-five subdivisions dealing with all the more important aspects of land utilization from the administrative, economic, practical and scientific points of view. The chief subdivision within the Department concerned with the prevention and control of erosion on agricultural lands is the Soil Conservation Service, the functions of which involve research into the problems of soil erosion and its control, and the propagation of erosion-control practices through the medium of practical demonstration. In its task of administering the national forests, the Forest Service also plays an important part in the conservation of soil and vegetation, particularly in co-operating with States and private owners of forest and woodlands, in management of the national forests, and in research, carried out at the national Forest Products Laboratory and at twelve forest experiment stations throughout the country. The pasture and range research of the Division of Forage Crops and Diseases, Bureau of Plant Industry, has also a direct relation to the conservation research.

The Soil Conservation Service conducts an extensive programme of research at the Soil Conservation Experiment Stations, each of which is located in a typical problem area, characterized by a particular type of climate, soil or agriculture. The investigations provide for the determination of soil and water losses which result from different land-use and farming practices under the wide range of conditions occurring in the continent. As conservation practices are developed and tested on the stations, they are applied to farms co-operating in the 'project' scheme, which involves the enrolment of as many farms as possible in a selected drainage basin on the basis of a co-operative agreement for the introduction and maintenance of recognized conservation practices as a demonstration to the farms of adjacent districts. Since January 1937 the soil conservation projects have been gradually replaced by the 'districts'.

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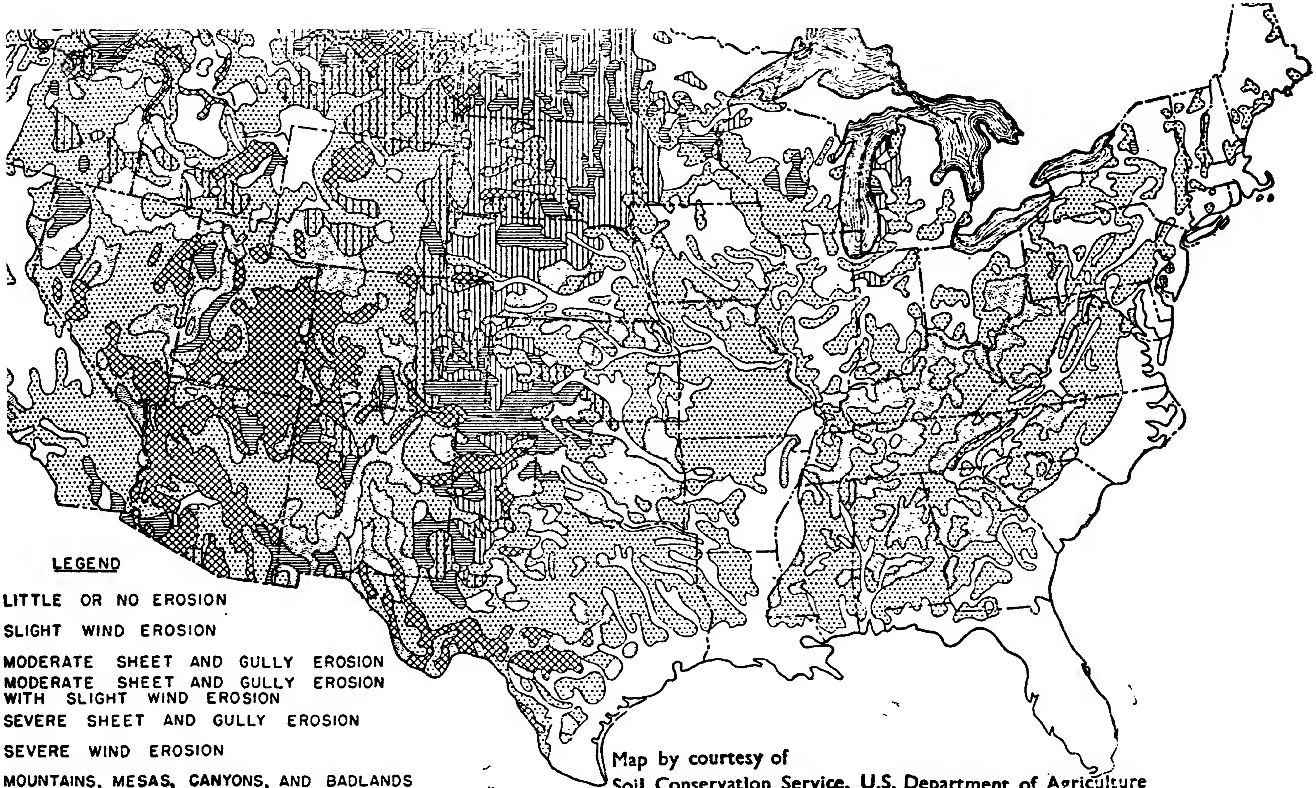
5. Natal. Gully and sheet erosion followed by the encroachment of bush on abandoned agricultural lands. See pages 63-66.

co-operating groups of farmers permitted by enabling acts to organize and form soil conservation districts which have the status of governmental subdivisions of the State. After a district is formed and granted a certificate of organization from the State, farmers then have authority (1) to engage in co-operative action to combat erosion, and (2) to prevent local misuse of land by voting land-use regulations upon themselves, similar to the ordinances which every city, town or county may adopt (e.g. town-planning). All land-use ordinances must be submitted to a referendum and publicly approved before they can be given effect.

In addition to the Soil Conservation Service, the Forest Service, and the Bureau of Plant Industry, other branches of the Department of Agriculture are directly or indirectly concerned with agricultural conservation, e.g. the Bureaux of Chemistry and Soils, Animal Industry, Biological Survey and Agricultural Economics, and the Extension Service. Many other aspects of the conservation problem are receiving attention in the United States, however. As examples may be quoted such diverse subjects as conservation in the special circumstances of the Indian Native Reserves, comprehensive schemes of flood control, prevention of siltation of reservoirs, rivers and harbours, the relation of highway construction to soil conservation, control of malaria, and the conservation of wild life in its relation to soil and water conservation and as a supplementary economic 'crop'.

It is thus obvious that with the collection of reliable scientific data from the innumerable experiments on such a wide range of subjects the American conservationist is becoming increasingly well armed for his fight with the erosion menace. The rest of the world, still lagging in the accumulation of scientific data, should also derive much benefit from the American work, and already a great number of foreign agriculturists have visited the United States to study their methods and see their experiments. The great variation in climatic and ecological conditions in the different parts of America is an added advantage in this respect. A brief summary will therefore be given of the characteristic problems of the different regions in the United States and of the methods being adopted in the development of a conservation economy.



Map by courtesy of
Soil Conservation Service, U.S. Department of Agriculture

The erosion problem in the north-eastern part of the United States is generally not so severe as in other sections, and is one of prevention rather than cure, namely, the prevention of further soil and water losses by the various recommended methods. These are reforestation, establishment and maintenance of good pasture and forage crops; contour strip farming; retirement of steep lands from cultivation; proper care of tree lands; the use of soil-building crops; maintenance of crop rotations; careful engineering. Deforestation has been excessive in some areas, and steep slopes have been cultivated which should not have been cleared. In the cultivation of arable land, the correct cultural practices have not been observed; rotations suited to local requirements have not been used, ploughing and cultivation have been done up and down slopes instead of on the contour. Mismanagement of pastures has led to deterioration of botanical composition with a consequent increase in the proportion of bare ground subject to erosion. Like so many parts of the United States, the area is subject to torrential rainfall over short periods. In a region where the production of milk is so important for supplying the great centres of population, pasture improvement is obviously of primary importance.

Further south, a particular type of conservation work has been in operation in the Tennessee Basin for some years. This is administered by the Tennessee Valley Authority (TVA), and extends over a natural region of about 40,000 square miles, with a population of 2,500,000. Originally the whole region was forested, but subsequent clearing for agricultural development has led to erosion, which has seriously impoverished most of the agricultural land. The organization of the TVA is described in Chapter XIX.

Some of the most sensational gully and sheet erosion to be found in the United States has occurred in the Piedmont country lying in the five States of Virginia, North and South Carolina, Georgia and Alabama, a region covering about forty million acres; according to the reconnaissance erosion survey completed in 1934, over three-fourths of the topsoil has been

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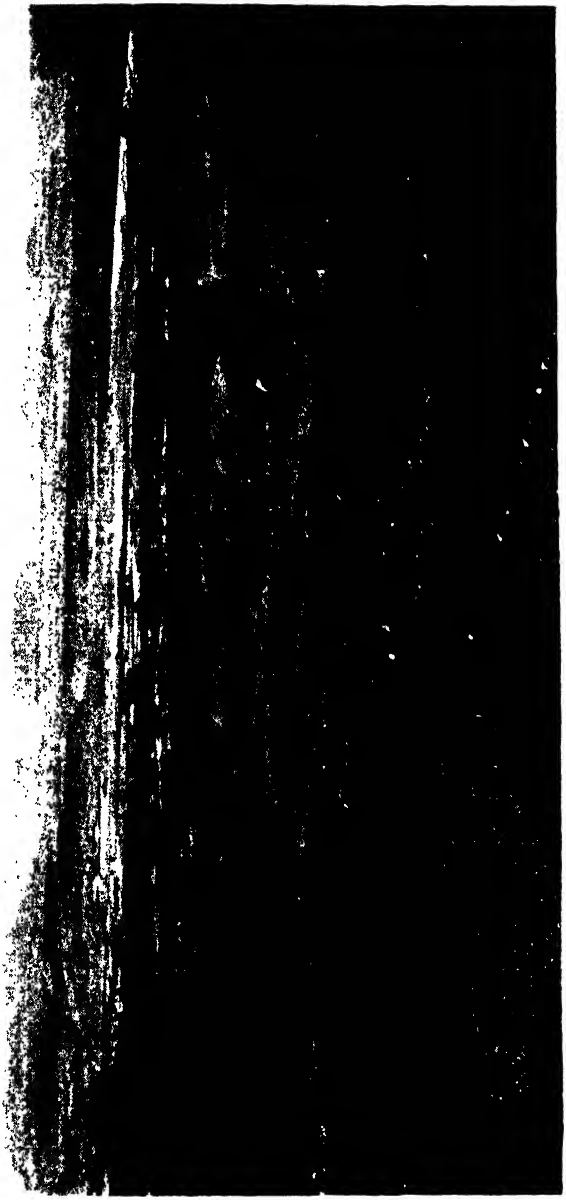
6. Natal. Sheet and gully erosion due to native cultivation and overstocking. See pages 63-66.



washed from about twelve million acres and great sectors of the area are disfigured and defaced by gullies (see frontispiece). Most of the remaining twenty-eight million acres have suffered in varying degrees. The degree of damage caused by erosion increases as one goes southward; there are millions of gullies in the Piedmont. In some types of soil, gully cutting goes on slowly, in others, especially those derived from granitic rocks, the process, though slow until the clay subsoils are worn through, becomes rapid when the soft, 'rotten' or disintegrating rock which underlies the clay is reached. Advanced erosion accounts in a large measure for the retirement from cultivation of some 50,000 farms between 1920 and 1930, in the Piedmont of the Carolinas and Georgia.

As a result of this excessive erosion, bottom lands have been buried by the deposition of eroded material; in an area famous for its water power resources, thirteen out of fifty-six of the larger reservoirs in the southern Piedmont are now completely filled with silt.

The broad base terrace was developed in this region, first in the form of the Mangum terrace and more recently as the Nichols terrace.

The Upper Mississippi Region of the Soil Conservation Service (Region 5), comprising the States of Minnesota, Wisconsin, Illinois, Iowa, and Missouri, contains half the first-grade land in the United States. This is the famous Corn Belt, where corn or maize has been grown continuously for many years. Very small amounts of legumes have been grown in rotation, with the result that the organic matter content of the soil is seriously depleted and the soil made more erodible. The absence of a leguminous crop in the rotation leaves this erodible soil exposed to water erosion at critical periods of the year. In a typical area 15 to 30 inches of the topsoil have been removed.

As in so many parts of the United States, it is the land tenure system which is chiefly to blame; practically all the farmers are

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7. Orange Free State, Pinekloof. Bird's-eye view of vlei and erosion-control works at lower end. The dam in the foreground has a smaller dam above it. Contour channels lead the water away from the wings of the lower dam and distribute it over the slopes. See page 66.

tenants, the rent for their farms (often not more than 100 acres in size) being on a crop-share and a cash basis. The cash payment on the basis of the house, the buildings and the pasture land is about ten dollars per acre. The crop-share system is adopted for the land in crops and the farmer is therefore not encouraged to put land in pasture or clover. The crop-share lease encourages crop, and particularly corn, cultivation; leases of this type usually run for one year only. Stock-share leases place the emphasis on livestock, particularly cattle, and on pasture and hay crops, and are usually long-term leases. The usual stock-share lease is not well adapted to dairy farmers, and an improvement in this direction would facilitate erosion control. A cash-rent lease affords the tenant complete freedom, provided the rent is adjusted to the price level.

In the Great Plains States, depression and drought have only accentuated a situation which has long been developing. The settlers of the Plains attempted to adapt the recognized agricultural practices of the more humid regions from which they came to an area where the rainfall is around, and for considerable periods below, the critical level at which it is possible to grow crops by these methods. The new agriculture which is being slowly developed is based upon the conservation and effective utilization of all the water available. The conservation of moisture is further facilitated by the Great Plains project to plant shelterbelts on about 1,000,000 acres of farm land within a zone 100 miles wide extending through the prairie plains region from the Canadian border into the Texas Panhandle.

The chief problem in the Great Plains Regions and particularly in the Southern Great Plains is the control of drifting and blowing of soil. The control measures representing successive lines of defence against wind erosion are:

1. Utilization of erosion-resisting crop residues.
2. Moisture conservation for maintenance of vegetation.
3. Emergency cover crops.
4. Windbreak tree planting.
5. Emergency tillage operations.

The ideal system of management would require the maintenance of a vegetative cover until soil moisture sufficient to

ensure the successful start of the next crop has been accumulated in the soil. The accumulation of soil moisture is further facilitated by terracing, contour tillage, contour and basin listing (ridging), and contour furrowing on pasture land. Further relief can be provided by water storage in reservoirs and dams for livestock and irrigation purposes.

The native forage-producing lands in the United States suitable for use by livestock cover a total of 728 million acres, or about 38 per cent of its area. The range country lies in the western half of the United States and consists almost exclusively of lands which are unsuitable for any other form of agriculture because of the relatively meagre precipitation or other adverse climatic conditions, rough topography, or lack of water for irrigation. Within this range territory nineteen million cattle and thirty-six million sheep and goats graze for part or all of the year and produce 75 per cent of the country's total yield of wool and mohair, 55 per cent of the sheep and lambs and nearly one-third of the cattle and calves. Owing to the low precipitation[1] (averaging fifteen inches per annum), high evaporation and other adverse factors, range forage production is small, as compared with that of humid pastures. On the best of range lands two acres are required to support a cow for a month, while on the poorest, twenty or more acres may be required. In addition, recurring drought makes sustained forage production uncertain, requiring still more conservative grazing.

Through overgrazing in the short space of fifty years, much of the grazing value of the range has been seriously depleted and even now stockmen are attempting to graze approximately seventeen million animal units on range having a sustained grazing capacity of about ten or eleven million units. All but two of the principal range types are depleted by half or more. The tall-grass range depleted by only 21 per cent reflects especially favourable growth conditions. The open forest type, with depletion of about 33 per cent, also reflects favourable climatic conditions and national forest management. The salt-desert shrub, southern desert shrub, and sagebrush-grass types all reflect critical growing conditions and loss of grasses from excessive grazing.

[1] Fall of moisture in the form of dew, rain, snow, etc.

An important factor in depletion has been the unsound land policy under which 100 million acres or more of submarginal land have passed to private ownership, regardless of character, much to be cultivated unwisely. The successive waves of failures, reduced standards of living, the defeat of hopes and ambitions, the abandonment of homes, closed schools and churches, widespread tax delinquency and large acreages reverted to counties and States, furnish an indication of the effect of unrestrained exploitation and range destruction on social well-being.

Erosion control in the South-Western States is carried out on the various Indian Reservations and other areas, the projects here being very large, in the vicinity of fourteen to seventeen million acres. Material progress has been made in the development of sound land-use schemes permitting the users of Indian land to carry on operations without shifts. Water spreading, by the construction of extensive dams with special outlets (spillways), and range revegetation are now the chief lines of operation.

In California the problems are over-cultivation on excessively steep slopes for bean growing, erosion in orchards, deterioration of the vegetation of the mountains due to overgrazing and fire. This has led to serious erosion in many parts, and to flooding on the scale of the Southern California disaster of 1938. According to Dr. W. C. Lowdermilk, the cause of the principal damage of this flood was the debris in the flood flows, consisting of trees, boulders, gravel, sand and soil. 'The run-off flows were sufficient to load up to capacity the current to carry such debris and as these currents progressed downstream slight flattening of gradients was sufficient to cause the streams to unload. This unloading process dammed up channels and caused the streams to break out on the one or both sides of such obstructions. Thereupon, the streams wandered across areas occupied by buildings or citrus orchards and in turn picked up new loads of soil later to be unloaded and deposited in dwellings and on agricultural lands. Run-off from steep areas, particularly those which had been recently burned over, produced remarkable mud-rock flows, in which the solids were found to be two and one-half times the water content.' If it had not been for the effect of debris in the flood flows, it is doubtful whether any serious damage would have occurred.

To quote Raymond Swing again, the experiment of transforming the agricultural economy of the United States is the greatest that the Americans have ever had to tackle, but with the quality of the 'frontier' days remaining, 'one still feels that America is a land of unlimited opportunity,' although the nature of the opportunity is changing. 'It is more social to-day than individual, and the task of the future is to save and restore the continent.'

The Canadian erosion problem represents a continuation northwards of that of the prairie and Great Plains States of the United States. Soil drifting was first experienced at Indian Head, Saskatchewan, in 1887, and appears to have developed soon after the prairie lands were broken and seeded to grain. Except in a few areas where successful control measures were adopted, the intermittent occurrence of drifting from year to year and the more or less widely separated areas involved have probably discouraged any extensive attack on the problems During the years from 1931–1934 soil drifting became so serious and widespread that more definite action towards effective and permanent control became imperative.

Few areas on the prairie are entirely immune from soil drifting. The practice of summer fallowing, essential over the greater part of the prairie for the conservation of moisture, provides large areas of bare land which are susceptible to drifting. Extremely light and extremely heavy soils, such as sands and clays, appear to be more susceptible to drifting than loams. Southern Alberta, southern Saskatchewan and south-western Manitoba are the areas most susceptible, elsewhere there may be periods of several years between the occurrence of severe dust storms. Drifting usually occurs during the spring months of April and May, and occasionally during June, although it is not infrequent in southern Alberta even during the winter months.

In addition to the damage to arable lands, there is considerable overgrazing in the ranching areas, although they are in general better preserved than in the United States. It is, however, probably true to say that overgrazing on the prairie has not been sufficiently severe to result in erosion except in certain sandy areas.

Official action has been taken, by the passage through the Dominion Parliament in 1935 of the Prairie Farm Rehabilitation Act, to provide for the rehabilitation of the drought and soil drifting areas in Manitoba, Saskatchewan and Alberta. Appropriations of $750,000 were provided for the fiscal years 1935–36 and 1936–37, and of $2,000,000 for the fiscal year 1937–38.

The measures adopted under the Act encourage farmers to adopt improved cropping and cultural practices through the agency of the Dominion Experimental Farms, District Experiment Sub-Stations, and Agricultural Improvement Associations. Strip farming, cover crops, and the ploughless fallow are being promoted in order to check soil drifting. In addition, farmers are helped to secure seed of drought-resistant grasses, and trees for shelterbelts, and to develop water facilities for livestock and domestic uses. In connexion with this programme, a considerable amount of research work on drought and soil drifting is being conducted both on the Dominion Experimental Farms and on new District Experiment Sub-Stations and Reclamation projects.

Although there is certainly water erosion in Eastern Canada, on the Peace River tableland, and in British Columbia, the problem in these areas is not yet as urgent as that of wind erosion in the prairies.

Unregulated felling of privately owned forests in the chief forest areas of the United States and Canada is still an important factor to be reckoned with in the conservation of soil and particularly in the control of flooding. Hitherto forest resources have been considered to be inexhaustible. Already great areas of forests in the United States have been cut and milled without regard to their restoration; Mr. F. A. Silcox cites many examples of towns and villages where all the recognized improvements of modern civilizations have been provided for populations of several thousands dependent on the exploitation of these resources. These centres of population have disappeared or have been reduced to insignificance. There is a definite danger of a repetition of this type of occurrence in British Columbia; the authorities are aware of the possibilities of forest devastation, and legislation and forest reservations are now being adopted both here and in Eastern Canada; nevertheless,

much has yet to be done. It must be decided whether the forest services or the lumber interests are in charge or control of the forests, before any degree of permanent stability can be acquired by an industry whose export trade had a value of fifty-five million pounds per annum before the depression, and even now is in the vicinity of thirty-two million pounds.

In the United States, President Roosevelt has emphasized the situation regarding private forests and has made recommendations on the question of their protection from fire, insects and diseases, and on the desirability of introducing measures, federal and state, to ensure that timber cropping on privately owned forest lands may be conducted as continuous operations, with the productivity of the lands built up for future requirements.

Little information is available about erosion in South America, Deforestation is becoming an important problem in Brazil. where a practicable Forest Code is disregarded and large areas are cleared for cultivation or to provide fuel or grazing land. The soil fertility in the Argentine is known to be decreasing with the continuous removal of animal products and the neglect of adequate use of manures and fertilizers, and erosion may ultimately follow. The classical example of mountain terracing in Peru (Fig. 23a) stands as a lesson to modern soil miners.

Different factors are concerned with the erosion which is occurring in many of the islands of the West Indies. In Jamaica, small tenant farmers have practised shifting cultivation, paying rent for, say, one acre but burning and destroying forest over a very much larger area. In addition, accessible areas of forest have been heavily over-exploited, and there are insufficient Forest Reserves. In the plantation districts all land fit for this type of cropping has been cleared, but in addition excessively steep slopes have been disposed of to petty settlers, for the production of foodstuffs.

A reconnaissance survey of Puerto Rico has shown that there is slight erosion on 19 per cent of the island, mostly on cultivated parts of the coastal plains and alluvial valleys or on gently rolling pasture lands; moderate erosion was found on 29 per cent and severe erosion on about 39 per cent of the area. Most of the severe erosion occurs in the rough mountainous interior.

Sheet erosion is the most common type, with gullies occurring on a little less than 22 per cent of the total area.

Deforestation has also been excessive on some of the Windward and Leeward islands. For example, a critical stage has been reached on the island of St. Vincent, the prosperity of which depends upon an adequate perennial supply of pure water, particularly necessary for the arrowroot industry; most of the world's requirement of this commodity is supplied by the island. This industry is now threatened by a shortage of clean water; the development of the banana industry and a knowledge of what has happened in Jamaica make it easy to foresee an increasing pressure upon the forest land and an increased load of silt in the rivers.

In Trinidad, felling of protection forests and shifting cultivation have caused serious denudation, erosion and severe flooding in the Maracas Valley and the Caroni plain.

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8 *a*. A large gully on Mr. Howard Hobson's farm. The gully (donga) was formed by flood water pouring down the sides of the eroded channels and was eating rapidly into the land (upper picture). See page 66. 8 *b*. The donga was dammed and the flood water now passes harmlessly over the eroded bank, to be distributed over grassland before returning to the drainage channel, where it is again treated in the same way (lower picture). See page 66.

CHAPTER IV

Africa

Africa deserves first place. Desiccation, shortage of water and the 'advance of the desert'. The transformation of South Africa into semi-desert in the twentieth century. No proof of climatic change to account for droughts. Controlled veld management and the contour furrow. Mr. Howard Hobson's reclamation work. The importance of Basutoland. Southern Rhodesia. Overstocking in Tanganyika. Tsetse. Density of population due to immigration into Nyasaland. Uganda. Soil Conservation Service organized in Kenya. Erosion still gaining momentum. The encroachment of the Sahara. Abyssinia. British Somaliland.

The African continent has been recognized more slowly than the American as a great area of active erosion, although it does not in any way merit a relegation to second place. When the seriousness of the North American position became recognized, the great publicity connected with the national conservation drive, both in the American Congress and in the Departments concerned, caused the American problem to become well known and appreciated, almost to exaggeration, throughout the world. Now that the forces of erosion are being slowed up in America and Canada and a conservation economy is being slowly developed, it is probable that Africa will take the foreground.

In order to indicate the relative extent to which deforestation, overgrazing, excessive cultivation and other factors have led to erosion and desiccation throughout the continent, a brief

9. Orange Free State, near Bothaville. Beginning of an attempt to control a donga; contour furrows stop head-stream erosion and other contours lead the water away from the donga. See page 66.

account will be given of the conditions at the present day in the various countrics of Africa. The rate of progress in dealing with the problem is slow, due partly to the wide range of conditions to be covered and a tardiness in the development of principles of a conservation economy adapted to the climatic and social conditions, but chiefly to the slow realization of the actual dangers by the governmental and administrative authorities. Throughout the continent erosion is still in the process of gathering momentum; the damage which has been done in the past five years may be equalled in the next two or less. In spite of this ominous outlook, many conservation works and experiments are hindered by lack of funds and staff.

The characteristics common to all parts are the destruction of the vegetative cover accompanied by gully, sheet or wind erosion, increasing desiccation, shortage of water for human, animal or irrigation purposes, and a general sinking in the level of the ground-water table. The factors causing destruction of the vegetation differ in forests and grasslands. The processes of deterioration have been initiated in many virgin forest areas by the practice of shifting cultivation; this native custom in its original form was not dangerous, but with increasing settlement, and more frequent return to the same plot, the soil is not being given time to become revegetated and thus to regain its fertility. As a result the vegetation deteriorates from its natural climax forest type to a degenerate forest or a savanna containing remnants of the original tree flora. Cropping becomes impossible owing to loss of fertility and animal grazing is introduced. This, combined with periodic burning, perpetuates the processes of regression and the grass flora of the savanna becomes poor and sparse. The progress towards desert conditions is completed by the goat.

In grassland areas overgrazing is caused more by badly distributed stocking than by overstocking; the practice of kraaling adopted in South Africa, and the difficulty of obtaining sufficient water holes in East Africa, are factors leading to maldistribution. Burning of grassland is also an important cause of deterioration; this practice is adopted to provide fresh young growth or to burn off unpalatable standing grass, to clear grass which constitutes a fire danger on the edges of forests, and to

assist hunters. Although uncontrolled burning is a dangerous practice, our knowledge is still insufficient for us to say in what circumstances and at what times of the year burning can be adopted without harmful effects on the vegetation and on the surface of the soil, particularly the humus layer.

Throughout Africa, and more so in the countries bordering on the Sahara, the problem of increasing desiccation (the so-called 'advance of the desert') and shortage of water supplies is becoming ever more acute. The deterioration of the forest through savanna to poor grassland and ultimately to bare ground has a disastrous effect upon the water relations of the many areas where it is occurring. The loss of equilibrium in the ecological balance means a disturbance in the hydrologic cycle (see page 189), particularly in the direction of a great increase in evaporation from the soil surface and a great decrease in the amounts added to the valuable underground reserves in the ground-water table. Thus, as in many similar parts of the world, the rainfall is not so much decreasing as becoming less effective, due to increased run-off and evaporation. The urgency of stopping the sinking of the ground-water level cannot be over-emphasized; all schemes of rehabilitation and revegetation will be of little avail if these resources are depleted.

Another aspect common to many countries in Central Africa is the connexion between soil erosion and tsetse fly control. Until recently soil conservation and fly control tended to be antagonistic, as fly control necessarily entailed the clearing of large areas of infected forest, thereby exposing the soil to erosion. The present outlook is, however, more promising, as it is considered that by selective felling, leaving trees of a certain height or type, it will be possible both to control the fly and retain the protective forest cover. The difficulty associated with this is that it is a highly skilled job to know how the felling should be done under the wide range of climatic and altitude conditions. Tropical forest management as practised to-day is a very crude art compared with European forest management.

Although South Africa's chief source of national wealth is its mines, the pastoral industries are the most important agriculturally. The natural veld and, in the more arid parts, the karroo vegetation provide and will continue to provide most of

the animal fodder, supplemented by special cultivation of grasses and forage crops in favoured localities or at suitable periods of the year. Erosion has already transformed parts of the richest pastoral areas in the country into semi-desert. Considering that the luxuriance and excessive wetness of the veld in the Orange Free State were previously an obstacle to pastoral farming, the rapid appearance of the disastrous consequences of erosion is very remarkable. It occurs in all parts of the Union, either as an actual or probable menace, and is predominantly a pastoral problem.

The great uncertainties of the South African climate, and the suddenness with which the country was opened up after the discovery of gold, have contributed largely to the rapid acceleration of erosion. Towards the end of the nineteenth century it was realized that serious overstocking was taking place, but public attention was not focused on the danger until the Drought Investigation Committee issued its final report in 1923. Until then the opinion had been gaining ground that the climate was becoming drier and the rains more torrential. The report pointed out that there was no proof of a definite and recent climatic change, but that erosion alone would account for the drying up of rivers and waterholes, the falling water-table and the increasingly disastrous effects of droughts and heavy rains. The Commission concluded that the erosion was caused chiefly by deterioration of the vegetative cover brought about by incorrect veld management, and that all efforts to improve the latter would have a beneficial effect on the former.

The worst features of veld management are kraaling, overstocking, and indiscriminate burning. Kraaling is practised as protection against jackals. It forces stock to lead an unnatural

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10 *a*. Basutoland. Photograph taken on April 4, 1937, of proposed site for dam at Matsieng at the junction of three main dongas (looking upstream) at commencement of work. See page 67. 10 *b*. Basutoland. Photograph taken on January 5, 1938, from top of dam when full. Dam holds 6½ million gallons of water, to which cattle have access for drinking. Nearest water used to be five and a half miles away. The bank contains 1,819 cubic yards of material and cost about £47. See page 67.

life, weakens their constitution, increases their food requirements and destroys the pasture in ever-increasing radii around the kraals. Overstocking and the resultant overgrazing are frequently caused by extreme variations in climate, and the farmer's optimism in stocking his land on the basis of a good season. Veld burning is an old custom which has damaged or completely destroyed the natural vegetation, especially on mountain slopes. It may be permissible on sour veld, where it seems to be the only practical means of controlling surplus growth and preventing reversion to forest, but on sweet veld it should be dispensed with altogether.

Other causes of erosion have included deforestation, particularly by the natives for timber or firewood, and the construction of roads and railways without regard to control of storm water. Clearing for tsetse fly may be necessary in North Bechuanaland and Zululand, although fly trapping is an alternative.

The South African climate and relief are such that less than 15 per cent of the land area is suitable for, and less than 5 per cent under, cultivation. The country is, and apparently always must be, predominantly pastoral, and by far the most important problem confronting pastoralists, and perhaps the whole nation, is how to prevent sheet erosion by maintaining an adequate vegetative cover through controlled grazing. The official attitude seems to aim at discovering, and then if necessary enforcing, the best principles of pasture management, rather than at indiscriminately discouraging or prohibiting kraaling, veld burning and other practices which are ingrained in the South African's attitude to the land and may ultimately find a restricted place in a suitable pastoral system, which must be determined for each region according to the prevailing soils, vegetation and climate. Any economic and political measures such as the fostering of urban activities to relieve the land overstocked by men

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11. Basutoland. Photograph taken at Matsieng on June 9, 1937, from top of hill in fenced area looking due south towards the paramount chief's village. Contour ridges were constructed in December 1935; dam just completed. Trees were planted on the plough furrows drawn between the contours. See page 67.

and animals, or the State purchase of derelict farms, are stated to be useless unless they are supplementary to the controlled veld management which is the crux of the whole problem. With the aim of developing such a system the problem is being studied from the ecological and practical (e.g. pastoral systems) points of view. J. W. Rowland considers that detailed studies of ecological succession under modern grazing conditions combined with careful limitation of grazing are the only sure way of controlling veld deterioration and erosion. The natural flora under free grazing conditions was quite different from that which can survive under modern grazing systems. Only a careful study of plant succession under different grazing conditions can show which system is best suited for each type of locality. Fencing may be essential in many cases to obtain complete control over the veld and to allow rotational grazing, but many areas have gone too far to be reclaimed by grazing control. T. D. Hall sees in the contour furrow or ridge terrace one of South Africa's great hopes for the future. The ridge terrace is especially useful on gullied land, where it is cheaper and more efficient than damming. It not only restores and irrigates the veld, but also controls flood waters, reduces silting, prevents dams from breaking and rejuvenates springs.

Successful reclamation work is being carried out by Mr. Howard Hobson at Vinies, Orange Free State; the existing gullies (dongas) are used as water reservoirs by filling them with water. This avoids the costly process of filling them with earth. Thereafter excess water flows harmlessly over the top of the dam and the farmer secures a valuable water supply. There is said to be great scope for the application of these methods in conjunction with the recognized principles of contour construction. Similar methods are used with success in Basutoland.

Government action in South Africa has been chiefly concerned with giving State assistance for gully reclamation; it is considered that the problem of tackling gully formation at its source, by controlling sheet erosion and flood waters on the watershed, can at present be accelerated more by education and research directed towards improvement in such matters as veld management and maintenance, forest and watershed protection, than by direct financial assistance.

Since 1933 five government schemes have operated, whereby the State in various ways meets part, or all, of the cost of the construction of anti-erosion works, the purchase of implements, or the erection of fences to protect trees and shrubs planted as a conservation measure on eroded areas. The schemes have not entirely fulfilled their original purpose, more attention having been paid to damming than to contour banks, gully repairs, and so on.

Schemes have also been instituted to assist the reclamation of wind-eroded lands, both in the inland regions and along the coast. Temporary plantings of grass and other protective vegetation have been made, with a view to the permanent establishment later of a scrub or tree vegetation, the only type which can be relied upon to retain drift sand sufficiently.

Steps are also being taken for the State purchase of large areas in the mountains of the Union, the object being to prevent the further abuse of these lands in private hands by overgrazing, burning and ploughing on steep slopes, and thereby to assist in the prevention of increased desiccation through excessive run-off and floods. All mountain land bought by the Government will be administered by the Forestry Department, the natural vegetation being given appropriate protection, supplemented by special plantations.

The conservation works in the Union itself are intimately connected with control in the three Native Protectorates, especially Basutoland, which contains the dominant watershed in South Africa. A sum of about £160,000 has been allotted from the Colonial Development Fund for the ten-year programme of erosion control in Basutoland. An ecological survey of the mountain area of the Protectorate by R. R. Staples and W. K. Hudson has shown that no overstocking need occur, provided the present numbers of cattle are not exceeded and are properly distributed. Wholesale overstocking may become general again and action is necessary to avoid this.

In Southern Rhodesia, sheet erosion is severe on the oldest best and cultivated soils in the northern districts of Mashonaland. Soil conservation measures are now being accelerated as much as possible by ridge terracing and other means. Gully erosion is extensive on range land and in native reserves, prin-

cipally in Matabeleland. Veld burning, clearing and subsequent abandonment of bush land after a few years' cultivation, and the communal system of land tenure are factors which influence erosion in Southern Rhodesia.

Impetus was given to the conservation movement in 1932 by the publication of the Report of the Soil Erosion Committee appointed by the Rhodesia Agricultural Union. On its recommendation, Central Soil Conservation Advisory Councils have been established in Salisbury and Bulawayo, and a system of district sub-committees has been formed. A Soil Conservation Act is under consideration. Free technical advice and assistance are given by government engineers, and financial advances for conservation and irrigation works are made on easy terms. Limited quantities of kudzu vine, spineless cactus and certain creeping grasses are issued for control of excessive washing. In the native areas, the Native Department employs a soil conservation officer and a considerable staff for educative and constructional work. Contour ridging and draining are proceeding on the worst eroded areas.

Northern Rhodesia is sparsely settled by Europeans and the greater part of it is under primeval forest. Erosion is not a pressing problem, but conservation precautions are being taken to guard against future eventualities.

A committee was formed in Tanganyika in 1931 under the chairmanship of the Director of the Amani Research Station to advise on the problem of erosion. This committee concluded that in the absence of sufficient funds for a direct attack on the problem the endeavour should be educative rather than directly ameliorative. While Government was prepared through its officers to demonstrate methods and systems for arresting erosion, it was not prepared to carry out extensive works, either to prevent erosion or to check deterioration in eroding areas. It is now claimed that people are becoming interested, some tribes and clans are convinced of the need for soil conservation and in due course desirable agricultural practices may be carried out as routine and custom. Possibly sooner or later general legislative measures may be necessary to bring a minority into line, but it is stressed that the time must be ripe before enforcement is applied generally by means of a territorial law. Meanwhile

conservation rules under the Native Authorities are being encouraged.

While appreciating the losses suffered by individuals through erosion and the danger to tribes and to water supplies in certain areas, it must be realized that the whole territory is not seriously endangered by man's disturbance of the land, for the total cultivated or exposed soil area is only about one-thirtieth of the whole. It is stated that 7 per cent of the area of the territory is suffering from overstocking. Thus at the outside only one-tenth of the area of Tanganyika Territory is affected, and some of that one-tenth is not really menaced. With so little proportionate disturbance, and considering the natural regeneration of which vegetation is capable over the greater part of tropical Africa, it is unnecessary to be pessimistic about the condition of the whole Territory. Nevertheless this one-tenth undoubtedly represents by far the most valuable fraction of the country.

According to the Director of Veterinary Services (H. E. Hornby), there is danger of a loss of perspective in the relation between erosion and overstocking. Soil erosion is not synonymous with overstocking; it may be due to many factors of which one is overstocking. From the purely native point of view, overstocking may even be a necessary evil, since it tends to produce aridity and to reduce the incidence of certain diseases; native stock owners may favour it, preferring seasonal losses from starvation, which they can understand, to continual and greater losses from diseases the nature of which is beyond their comprehension. The only hope of checking the growing evil which is accelerated by *laissez faire* is considered to be in some form of government intervention. The utmost importance is attached to the institution of rotational grazing, combined with the multiplication of water supplies, the control of grass burning, and a control of the type and numbers of stock which may use each of the units of grazing which would be demarcated and developed.

The work of the Tsetse Research Department is of importance in connexion with erosion. Many tsetse areas exist in the Central Provinces, especially where the fly has encroached on cattle grazing lands and driven the stock back into what was already overstocked land; again the tsetse is delaying the spread of

people from certain overpopulated areas. At the same time the presence of tsetse in many parts may be a blessing in disguise, as it can be regarded as acting as the trustee of the land for future generations.

The damage caused in Nyasaland by unsettlement, destruction of forest by fires and unregulated felling, and inferior methods of agriculture has been rapid and intense. Certain of the native tribes, immigrants or descendants of invaders, practised shifting cultivation; the resulting denudation of hillsides presents to the administration the greatest problem as regards food production. It may not be many years before the limit of possible food production will be reached. Important waterways have been silted up and much valuable alluvial soil washed away. Mountains and hills stand out as large masses of bare rock, treeless plains now extend over large areas and sections burn fiercely every year. The high density of population is an important factor, particularly as development in central areas has led to congestion in the highlands, and steep slopes are being cultivated everywhere. The average soil is capable of supporting 300 persons per square mile. The increase in the number of Anguru natives in Nyasaland from 120,776 in 1921 to 235,616 in 1931 is due almost entirely to immigration from Portuguese East Africa, even into districts where population density varies from 88 to 116 per square mile.

According to the Nyasaland Government Circular No. 3 of 1936, the following measures are required for the improvement of agriculture and for control in the use of the land.

(*A*) *Improvement of agriculture*

(1) Soil conservation; by terracing, draining, contour planting and contour bunding.

(2) Maintenance of soil fertility; by the use of cattle manure, compost, mulching and systems of rotations.

(*B*) *Control in the use of the land*

(1) Protection of major catchment areas and watersheds by means of forest reserves.

(2) Protection of stream banks and steep hill slopes under powers of the forest laws.

(3) Preservation of natural vegetation on the poorer soils of the country.

(4) Preservation of belts of forest and natural vegetation on the better lands, to form windbreaks.

(5) Maintenance of village forest areas which should normally occupy land unsuitable for (or less suited to) agriculture, for example, hill slopes and poorer soils.

(C) Measures complementary to A and B

(1) Prevention of settlement by immigrants.

(2) The redistribution of population where necessary.

(3) The opening up of unused land by well-boring and control of tsetse fly.

(4) The control of bush fires and insistence on the policy of early burning.

(5) The gradual suppression of finger millet cultivation by methods involving the burning of wood to heat the soil.

The tribal wars which were a characteristic of Uganda in the early days ceased with the advent of European administration. Medical and veterinary science controlled the diseases to a large extent, with the result that the human and animal population increased. Simultaneously trials of cash crops for export were made and thirty years ago it was becoming clear that cotton was the crop best suited to local conditions. To achieve and retain new standards of luxury the natives increased their plots of cotton, with the result that the area under cotton in the years 1916, 1926 and 1936 was 133,000, 533,000 and 1,500,000 acres respectively. The size of the individual plots increased and in some districts large communal plots were cleared every year with no intervening strips of bush or grass vegetation.

The increasing cattle population, which has resulted in widespread overstocking by pastoral tribes, likewise demands a larger grazing area, and has intensified the native practice of burning the grass and bush country in the dry season to stimulate the succulent young grass that comes up after burning. The common African difficulty is encountered here that the native is as unwilling to part with his animals as the white man with his money; attempts are being made to substitute cash for cattle

and at the same time to encourage a taste for meat, as it has been found that the standard of native health improves on an increased protein diet. The preservation of grazing land in the tall grass and short tree savanna country depends largely on the annual grass fire, since if this fails the country very quickly goes over to forest. Cattle in this type of country are never the primary cause of erosion, since if there is overstocking the grass is eaten short, the annual fire fails and forest supervenes.

The effect on erosion of introducing the plough must have been considerable; one serious result of ploughing has been the spread of clean clearing with the complete removal of bush roots and stumps. Clean-cleared land suffers badly from desiccation in the dry season, and much benefit would be derived from suitably situated windbreaks. Indeed, a general reforestation scheme has been suggested, as the irregularity and torrential nature of the rainfall are powerful eroding factors and are believed to have been intensified by deforestation. Protection forests are also required to regulate streamflow as well as for their direct influence in checking erosion. Notwithstanding the relatively high rainfall, five-sevenths of Uganda suffers from an insufficient water supply and there is reason to believe that as a result of erosion and other causes the general ground-water level is falling and the lakes are receding. Particularly urgent is the reforestation of the important and now badly eroded watershed in Karamoja, a district acting as a buffer between the desert regions in the north (Turkana) and the densely populated agricultural regions to the south and west. Noticeable desiccation of Karamoja has already occurred since its denudation. In several parts of the Protectorate the problem of the co-ordination of tsetse fly control (which necessitates clearing the bush) with soil conservation measures exists in an acute form.

The use of grass-covered contour bunds built on every second foot of contour, together with closer spacing, is being recommended for native cotton cultivation; experiments are being made with planted grass covers and green manures to ascertain how far the necessary resting period can be shortened and the general fertility level raised. Farmyard manure is also being tested as an alternative or a supplement to green manures.

A special Soil Conservation Service has been organized in

Kenya, under the Department of Agriculture, and surveys have been made of the degree and type of erosion in the different native reserves. Most of the earlier reports from Kenya dealt with the more accessible Ukamba (Machakos) and Kamasia Reserves, but it is now being shown that other reserves, e.g. the Kitui and the Emba Reserves, are as bad if not worse. The Turkana Desert is said to be spreading outwards at the rate of six or seven miles per year; this spread is due not so much to the influence of heat and aridity projected from existing deserts as to destruction of vegetation through overstocking and fire by herdsmen and primitive agriculturists on the fringe of the desert. This destruction is intensified by the occurrence of at least one and generally two severe dry seasons in the year. The establishment of a forest belt several miles wide and about 100 miles long might assist in extending the area affected by the local instability rains around Lake Victoria-Nyanza. The Karamoja district in Uganda and the West Suk districts in Kenya would be the areas to derive most benefit if this afforestation had the desired result of pushing back the desert.

In the moister districts of the Kikuyu and Kavirondo Reserves erosion is continuing in many places at a very rapid rate, due to the increasing demands made by the people on the land owing to (*a*) increased population; (*b*) increased desire to obtain cash through the sale of crops; cotton is the cash crop most conducive to erosion, followed by maize; (*c*) the absence over large areas of a suitable mixed farming system; (*d*) the cultivation of hillsides unsuitable for tillage; (*e*) lack of conservation measures in general; (*f*) concentration of stock in small areas; (*g*) subdivision and fragmentation of holdings under existing systems of land tenure.

In the European areas erosion is caused by exhaustion of the soil through long and continuous cropping without the adoption of measures to prevent erosion and maintain the humus content of the soil. The results of land misuse are only now becoming apparent in a grave form, as much of the land in the settled areas has been cultivated for only fifteen to twenty-five years.

Some areas in Kenya have already reached such a state of devastation that nothing short of the expenditure of enormous and quite impossible sums of money could restore the land for

human use above a bare and precarious subsistence standard. In such cases the only practicable policy is likely to be the resettlement of the natives under strictly controlled settlement schemes in more favourable situations, such as has been done by the Government in Tanganyika. It is, however, evident that resettlement of natives from devastated areas is possible to only a limited degree and for a limited time in Kenya Colony, in which there are not vast areas of unpopulated lands such as occur in Tanganyika. Generally speaking, erosion in Kenya has become serious only during the past ten years, but there has been a marked acceleration during the past five years. In addition to the causes enumerated above, the locust invasions of 1929–30–31 and the drought of 1931–35 greatly accelerated the process and were largely responsible for making it so apparent in the space of a few years. It is stated that erosion has become marked only since the coming of the European.

From the descriptions of the conditions in a few of the larger countries of Africa, it will be obvious that the position is serious and that an enormous amount of conservation work and education of both Europeans and natives is essential before erosion can be controlled. The threat of a succession of man-made deserts is a very real one to all parts of Africa, and not merely to those bordering on the Sahara itself. Professor Stebbing employs evidence of abandoned villages now lying in sandy wastes and the observations of French and British administrative officers to show that the desert has progressed southwards during the last few centuries at an average rate of about a kilometre a year. This progress of the Sahara requires further study, but the deterioration of the savanna country appears to be well established.

The problem of the encroachment of the Sahara has recently been investigated by an Anglo-French Forestry Commission in Northern Nigeria and the French Niger Colony. The Commission did not reach the same conclusions as Professor Stebbing. Silting up of streams and rivers has reduced the amount of surface water on the fringe of the Sahara, but this process is very slow and does not contribute an immediate threat to the prosperity of the West African colonists. Protection of headwaters, flood control, reservation of forests, and the reduction of shifting

cultivation in the drier parts can all play a part in delaying the deterioration. It is considered, however, that depopulation is due not to desiccation but to political and economic factors, inter-tribal wars, slave raiding and pestilence.

Reports of increasing desiccation also come from the countries on the northern border of the Sahara, e.g. in the Trans-Atlas districts of French Morocco, where cultivation is becoming increasingly difficult each year. In the Mediterranean countries, where the rainy season and the cold season coincide, the evolution towards desert conditions is less rapid than in tropical countries, but it is just as certain and not less difficult to reverse.

In the east we have Egypt clinging to the Nile Valley, dependent for its waters upon lakes and marshes, some of which are already affected by erosion, siltation and gradual drying up. It remains to be seen whether the Italian development of Abyssinia will be carried out with recourse to the basic principles of a conservation agriculture adapted to the conditions they find there. British Somaliland was threatened by wind erosion and the spread of a desert caused by overstocking by nomadic tribes, but the good results of temporary closure of grazing areas are a hopeful sign in the control of increasing desiccation.

The African problem is much more difficult to control than the American. No 'nation-wide' conservation programme can possibly be developed with so many different countries, races, climatic conditions, soils, agricultural methods, land-tenure systems and so on, but it is just these factors which make the development of conservation methods and systems so extremely urgent to all authorities concerned.

CHAPTER V

Australia and New Zealand

U.S.A. and Australia compared. Water erosion the most important economically. Wheat lands of New South Wales. Rate of erosion greater than in U.S.A. Water erosion in other States. Wind erosion in the semi-arid pastoral belt. Influence of rabbits exaggerated. Recovery in eroded pastoral areas. Drift in New South Wales and Queensland. Future of pastoral industry. Ranson Mortlock Laboratory. Drift in the Mallee. Deforestation. Need for erosion survey and co-ordinated action. The tussock grasslands of New Zealand. Sown pastures on deforested land. Grass seeding on burn to avoid erosion. Deforestation recognized as having been excessive. Control of floods and excessive soil washing.

The actual extent of erosion damage is much less in Australia and New Zealand than in the United States of America, when measured in terms of acres affected. Figures are not yet available as to the percentage of the cultivated land in Australia which is suffering from erosion, but it is probable that further investigations will show the extent to be far greater than is generally realized at the present time. The United States and Australia are practically identical in size (2,973,800 and 2,974,600 square miles respectively) but the figures for total acreage under crops differ widely (360,000,000 and 20,000,000 acres respectively). Australia thus has a comparatively small area capable of supporting a dense rural population, a fact which suggests that the soil on that area must be conserved all the more carefully, particularly if Dr. Madigan's hypothetical maximum population of 60,000,000 is even to be approached.

Although great stress has been laid on the effects of wind erosion, partly because it has been more spectacular in some areas and partly because it is more widespread, from the purely economic point of view water erosion is the more important

problem in Australia. A. G. Lowndes[1] states that in total economic loss the erosion in the wheat lands of New South Wales is probably more important than the combined effects of the other types of erosion in Australia. 'The wheat lands of New South Wales are the most extensively and seriously damaged areas in Australia. This is due firstly to the fact that in New South Wales most of the wheat is grown on undulating land with slopes of from 3 to 8 per cent, whereas in the other States the wheat lands approximate to plains. Again, in New South Wales the climatic conditions are more conducive to erosion than in the other States. In Victoria, South Australia and Western Australia the rainfall has a more marked winter occurrence and the intensity of individual falls is not as great; particularly in the wheat areas of north-western and central New South Wales summer thunderstorms are more frequent, and it is these odd thunderstorms which do the greatest amount of damage.'

According to E. S. Clayton, 'worse examples of water erosion are already to be seen in Australia in open grazing and cultivated lands than in the United States and Canada,' while Americans who have visited Australia have given the impression that the rate of erosion in many parts of that country, and particularly in the eastern half of New South Wales, is greater than in the United States.

Much of this land in New South Wales would now be recognized as too steep for cultivation, and would be safer as pasture, especially if contour furrows were employed. Many examples of erosion in orchards are known, particularly in undulating country. In the coastal dairy districts very rapid erosion follows cultivation of maize and fodder crops. The position with regard to water erosion in the cotton belt in Queensland also requires careful attention. Sheet erosion is widespread in Tasmania, particularly on the basaltic soils in the north; the southern apple-growing districts are also affected locally by severe water erosion.

Serious wind erosion has occurred in the semi-arid pastoral belt where the States border upon the central arid 'desert' region of Australia. F. N. Ratcliffe has made a special study of the problems which have arisen in this belt, which lies between

[1] In a communication to the Director of the Imperial Bureau of Soil Science.

the ten-inch isohyet[1] and the desert area centred in the Lake Eyre basin and embraces the greater part of South Australia, a considerable part of western New South Wales, the south-west corner of Queensland and the drier pastoral areas of Western Australia. The total annual figures of the very variable rainfall in these areas may mean very little, as much of the rain falls as light, ineffective showers.

More erosion and drift have occurred in South Australia in the 'bush' country (saltbush shrub steppe) than in the mulga scrub (acacia semi-desert scrub); stocking by sheep, and not rabbits or drought, have been the direct cause of the destruction of the protective plant cover. The saltbush country is fundamentally unsuited to stocking at a constant level, unless that level is determined on a 'poor season' basis.

Rabbits in association with drought usually receive the chief blame for soil drift, but F. N. Ratcliffe considers that their influence has been exaggerated, at least in connexion with semi-arid South Australian pastures. It is estimated that in the bush country, where drought is most extensive, the bush cover has been reduced to 10 to 25 per cent of its original density by overstocking, which has latterly been almost unavoidable after twelve drought years. Rabbit infestations occur only in good seasons and persist only as long as annual green herbage is obtainable; although the rabbits themselves do not seriously attack the perennial cover of saltbushes and bluebushes, they are certainly an accessory factor in that the sheep are forced to utilize the bush reserve before they would otherwise have done. In other words, rabbits cause symptoms of overstocking to appear at exceptionally low stocking levels. On the other hand, the vast sandhill areas of mulga (*Acacia*) scrub appear to be irretrievably doomed to drift unless the rabbit can be exterminated, as it effectively prevents regeneration of the scrub. The scrubland carries an ephemeral herbage vegetation and 'the only safe way of utilizing sandhill country is to stock it heavily while the flush of ephemeral feed is on (and the heavier it is stocked the less feed there will be for the rabbits), and to remove all stock completely before the plants have been eaten down to the roots and the surface cut about too much' (F. N. Ratcliffe).

[1]Line on Map connecting places of the same average rainfall.

Any appreciable degree of recovery in the eroded pastoral areas must depend upon a readjustment of stocking policy in the direction of light stocking which would permit the regeneration of the hardier native pasture plants. The large moving sandhills present the most difficult problem, as the more suitable native sand-binding plants are most susceptible to rabbit attack and are in any case slow in becoming established. Some exotic plant, preferably with a rhizomatous habit of growth, unpalatable to rabbits and capable of growing under an irregular rainfall of six to nine inches a year is needed. Research in progress at the Waite Agricultural Research Institute has shown that two plants in particular are likely to be of value in the reclamation of sand drifts in a Mallee area. Rye appears to be outstanding among the cereals and grasses for providing a temporary cover under conditions of limited winter rainfall on an area of moving sand. Reasonable yields of grain and dry matter were produced on drift sand in 1937 when the effective winter rainfall was 6·21 inches. The other species of value is African pyp grass (*Ehrharta villosa*) which must be planted from roots, but spreads rapidly in sand by rhizomatous development when once established, and permanently stabilizes drift sand in an area receiving ten to eighteen inches average annual rainfall, of which about 50 per cent forms the effective winter rainfall. Present investigations are designed to test the establishment of permanent herbage plants on a drift area temporarily stabilized by seeding with rye, and the influence of soluble phosphate and the seeding of additional pasture species on an area permanently reclaimed with pyp grass.

The South Australian Government has recently introduced a scheme for reducing pastoral rents with special consideration for lessees who agree to reduce their stock, fence off affected areas, and set aside permanent reserves for seeding native plants and trees. What more fundamental measures for saving the arid pastoral regions could be undertaken with reasonable hope of success is still an unsolved problem.

The position with regard to soil drift in New South Wales differs little from that in South Australia. The conditions in the former State may even be said to be worse than in South Australia, as unwise subdivisions of large holdings have been made

for closer settlement under unsatisfactory conditions. The fundamental problems are as difficult to solve here as in South Australia.

Four of the five main types of country in south-western Queensland were found by F. N. Ratcliffe not to be very subject to wind erosion. Sandhills represent the fifth type; these are naturally affected by wind and movement of surface sand is frequent, although the sandhills themselves are essentially stationary. The Queensland sandhills differ widely from those in South Australia; from the point of view of providing feed for stock, they are more productive than any other type of country found in that region, with the exception of 'flooded' areas. The South Australian drifts are markedly sterile, a fact which suggests a poverty of seed that might be counteracted by artificial means.

F. N. Ratcliffe concludes that 'stocking, as practised in Australia, must inevitably result in the progressive reduction of the slow-growing, evergreen fodder plants in semi-desert regions subject to frequently recurring droughts. And, in turn, the reduction of edible shrubs and bushes renders the country increasingly risky for the pastoralist, since the effect of droughts will, as a result, be more and more rapidly felt.

'It might be as well to point out that country stocked with cattle, at any rate country where breeding is not carried out to any great extent, should be less liable to suffer serious vegetational change than country given over to sheep. Wool production, on Australian standards, demands some continuity in breeding policy, and thus in the breeding flock; and there is accordingly every temptation to strain the fodder reserve to the uttermost in times of drought in order to avoid having to sell part or all of the breeding flock, which might otherwise be obviously desirable. Moreover, more expensive improvements are required on a sheep station than on a cattle run; and this sets a minimum economic limit to the flock which can be carried.

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12 *a*. Southern Rhodesia. Burnt-over forest. See pages 67-68.
12 *b*. Nyasaland. Makwapala, Zomba. Sheet erosion on land cleared from natural vegetation only two years previously. See pages 70-71.

'In extending pastoral settlement into arid and desert-marginal regions, Australia is in reality carrying out an experiment. The success or failure of that experiment will depend on how the problem of recurrent droughts is handled.'

An important step in the campaign against soil erosion and in the regeneration of pastures in areas of low rainfall in Australia was made in 1936, when a sum of £25,000 was presented to the University of Adelaide by the family of the late Mr. Frederick Ranson Mortlock. This gift provided for a suitable building to be erected at the Waite Agricultural Research Institute; the building was occupied in March, 1938.

Soil drift also occurs in the Mallee areas as the result of clearing the vegetative cover for wheat cultivation. Mallee soils are saline or alkaline, formed under a low winter rainfall and within the influence of the Southern Ocean. Drifting of light sandy soils occurs on a large scale in some districts of South Australia, Western Australia, Victoria and New South Wales. The drift in the Mallee has been accentuated by over-cultivation caused by high wheat prices and a succession of unusually good seasons after the War. Strip farming on the North American pattern has not been found to be adaptable to Victorian conditions; instead windbreaks are planted and various methods of introducing organic matter into the soil are employed, e.g. the sowing and grazing of oats.

The neglect of the principle of sustained yield in forest management was stated in the Report of the Committee which dealt with Australian forestry at the Empire Forestry Conference of 1928 to have resulted in the rapid exploitation of the forest wealth of Australia. In the 1935 annual forestry report from Queensland, it is stated that at the present rate of cutting, the stand of hoop and bunya pine remaining at the end of a decade will be of no great consequence'. It will apparently be many decades, if ever, before the timber of these pines will again be available in anything like the present annual amount. The relation between this excessive deforestation and the conservation of soil and water in Australia is obvious.

We thus see that, as regards the utilization of cultivated land,

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13. Kenya. Typical rain forest. See pages 72-74.

pastoral areas and forest resources, a great deal of damage has already occurred in Australia, the real extent of which can only be proved by an erosion reconnaissance survey carried out on the lines of the American surveys which brought home conclusively to research workers and administrators alike the appalling nature of the erosion menace to the American nation. That Australia is also threatened by a danger which is progressively gathering momentum there can be no doubt, and yet there appears to be a complete lack of a definite conservation policy for the country as a whole. A few part-time Committees are operating, but the number of full-time research workers is still negligible. As is being realized in many other countries, the only way to combat erosion is to work faster than it does, and this becomes increasingly difficult as time goes on.

New Zealand is famous as a pastoral country; of the 43,000,000 acres in occupation, 31,250,000 are in pasture, comprising 14,000,000 acres of native tussock grassland and 17,000,000 acres of sown pastures. The mountain tussock grassland of the South Island is still an important grassland area, used for grazing Merino and half-bred sheep. Of the tussock grasses, however, only blue grass (*Agropyron scabrum*) is palatable to sheep; this has led to the practice of burning to provide more palatable fresh growth. Indiscriminate burning, overstocking and destruction by rabbits have caused serious deterioration and in places the complete destruction of all vegetation. The improvement and conservation of this type of vegetation is an important problem, partly economic, since fencing and spelling are necessary for rejuvenation, and requiring also the introduction of exotic plants suitable for mountain soil and grazing conditions. Special attention may be devoted to a study of the various tussock species, before the source of seed of the more valuable species is lost to New Zealand agriculture.

The sown pastures of New Zealand have replaced large areas of forest; in fact, when the amount of deforestation which has taken place in New Zealand is considered, it is remarkable that the country has so far escaped serious erosion. Approximately 14,000,000 acres of forest have been felled and sown to grass in New Zealand; of this area, some 12,000,000 acres have been successfully converted to grassland, the remaining 2,000,000

acres reverting to secondary growth. In addition, some 2,000,000 acres of natural farm and scrub lands have been successfully grassed. Another 2,000,000 acres are still in natural fern and scrub and some 4,000,000 acres of standing forest await development.

A great deal of soil wash was prevented by the methods adopted of sowing the grass seeds 'on the burn'. The climatic conditions favoured rapid establishment, stocking with sheep and cattle being permissible about eight weeks after sowing. In the light of experience in other parts of the world, it is now being recognized that the destruction of forests has been excessive. Many of the hill areas are now under an inferior type of sward, and, although figures are not available for a comparison of run-off on these grassland and forested slopes, it may be expected that the run-off from the former would be considerably higher, and that therefore any further clearing, particularly along stream courses and on the watersheds, may accentuate the flood danger which is already present in many parts of the country.

The semi-arid areas of Central Otago present a special problem to the conservationist, as do other localized areas in the two Islands. According to Dr. E. Marsden, erosion has occurred in Central Otago, where the natural pasture cover has been destroyed by rabbits, fires or overgrazing and the soil exposed to fierce drying winds and periodic deluges of rain. It has also occurred where the bush has been removed from steep slopes and there has been extensive slipping, a common feature in Poverty Bay and many other districts. Where forest has been cleared and a grass sward established, the secondary growth is controlled to some extent by fires—a bad practice. Top-dressing of the sward is a possible alternative, but it is of doubtful economic value over the hill areas.

The most urgent problem in New Zealand, however, is the control of floods and the prevention of the excessive washing of soil down the short river courses into the sea, a process which threatens to leave the country like an 'emaciated skeleton'. Deforestation by cutting, burning, or overgrazing of the undergrowth in the mountain areas by sheep, cattle, deer and other animals has greatly accelerated run-off and soil wash, and there

is hardly a river in the country which is not affected by periodic flooding. The fact that these rivers frequently pass through rich dairying country combines with the mountain damage to make the conservation of soil, water and vegetation a pressing problem in New Zealand.

CHAPTER VI

The Orient

New and old erosion. India. The Punjab Siwaliks. Overgrazing and stock reduction. Traditional soil conservation. The need for co-operation. Plantation agriculture in Ceylon. China. The North-Chinese loess. Inadequacy of ancient terraces. Animal husbandry or depopulation. Yellow River floods. A superhuman task of flood control. China's old age. Japan's perilous position. The game and art of soil conservation.

In the three preceding chapters we have attempted to survey the deterioration of the land that has taken place in the more recently settled regions of the world as a consequence of rapid and excessive exploitation. The same phenomenon has appeared in the long-established countries of the Orient, where the consequences of recent exploitation are superimposed upon those of the land's senile decay. Recent exploitation has been responsible for much of the catastrophic erosion that scars the foothills of the Himalayas, but old age has also left its mark over wider tracts of India in the form of sheet erosion which has been going on for centuries. Prolonged rather than excessive utilization has ruined the land round the headwaters of the Yellow River in China—the worst eroded region in the world. In Japan erosion does not occur to any great extent, as the Japanese have learnt how to control it; the same is true to a lesser extent of Java and the Javanese, although the topography and climate of both countries produce conditions highly conducive to erosion. The Philippine Islands have long suffered from erosion which the native inhabitants—as in India—prevented from becoming catastrophic by primitive terracing and by adopting shifting cultivation. Large-scale sugar-cane agriculture and increasing pressure of population have made these antidotes less effective, and erosion has latterly become a grave problem.

The most potent and common causes of contemporary erosion in India are deforestation and overgrazing. The rapid increase in population since British occupation has greatly intensified pressure on the land, caused the cultivation of much unsuitable ground and shortened the resting periods between cultivation that are frequently necessary for the stability of tropical soils. The human population of India is increasing at the rate of about three millions per annum. Much of this increase is occurring in the tracts where nature in the first place provided easy conditions for human settlements, namely, a rainfall not too heavy for the ordinary farm crops, and natural grasslands in which cattle thrive and remain healthy. Within the heavy rainfall areas further east, the re-growth of dense tropical jungle and conditions inimical for livestock have discouraged dense settlement. Therefore much of the weight of this increasing population is falling upon the tension belt where grassland can persist only under reasonable treatment, and, if once destroyed, cannot reinstate itself as easily as it can under a slightly heavier or better distributed rainfall. Hence over very large tracts of country, natural grasslands have already disappeared and village livestock are dependent upon bush and tree growth for their day-to-day existence. In most other countries livestock are maintained on a ration of grass, and the bush growth which occurs in the grazing ground is looked upon as a natural reserve which should be used only in times of acute scarcity; in much of India the last vestiges of shrub growth already form the ordinary daily ration for the village herd. The amount of erosion caused directly through this state of affairs has to be seen to be believed.'[1]

Some of the worst erosion is evident in the Punjab Siwaliks, a range of hills skirting the Himalayas, where the hill grazier has accompanied or followed the woodcutter and effectively denuded the soil of its protective plant cover. In many places damage is not confined to the eroded slopes, further destruction being caused by torrents (*chos*) formed by gully erosion, that sweep down the slopes during the monsoon. The *cho* is characterized by the steepness of its gradient and the violence and irregularity of its discharge. The torrent carries much suspended material which is deposited on the less steep lower slopes in a

[1]R. M. Gorrie in *Herbage Reviews*, vol. v, 1937.

characteristic detrital cone which continually increases in radius and width. The *chos* debouching on to the cultivated sandy plains silt up the original drainage channels formed when hill erosion started, and the floods are forced out over wide areas. The floods subside as suddenly as they start, and all the water is lost to the land.

There is evidence that a hundred years ago the *chos* ran between well defined banks, and in some places perennial streams that could be used for irrigation issued from the hills. To-day, floods are the only source of water. Much of the subsequent erosion has been due to intensified exploitation that occurred when British rule secured some measure of prosperity and security. Reclamation might possibly be effected by closure of the land so that first grass, and then forest, could be re-established, but all the land is required to support the people, who have the right to use it, and the authorities have a natural aversion to interfering with jealously held rights. A drastic reduction in the surplus grazing animals is indispensable before any conservation programme can become effective.

Where erosion has been going on for centuries, the ryots have evolved farming systems which, although not completely checking erosion, have kept it to manageable proportions. The principal weapon against erosion is a crude earth embankment or *bund* whose primary purpose, however, is often not so much to prevent erosion as to stop a lower-situated neighbour's field from benefiting by rainwater and silt that would otherwise have flowed off the bunded field. As pressure on the land increases, bunding against erosion is being put on a more scientific basis. Extensive and successful bunding schemes have been carried out in the Bombay and Madras Deccans and in Central India, though recently they have been stopped owing to financial stringency. In many parts of India, indeed, the high cost of loans and the impossibility of getting any immediate economic return from reclaiming very poor and badly eroded land are seriously impeding soil-conservation work. 'Self-help' projects on a community basis in the villages appear to be the most hopeful solution for farm lands, but an adequate organization of such projects in a land of India's population and poverty would be a Gargantuan task. Co-operative action is not easily obtained

until erosion becomes a life-and-death matter to the community. Over much of India the people have accepted a slowly deteriorating environment as part of the scheme of things; the vast majority is probably unaware that erosion is occurring.

Tea and coffee plantations are usually well terraced against erosion nowadays, and clean weeding is not so rigorously practised in India as in Ceylon where it has caused untold damage. The rapid development of commercial tea and rubber plantations in Ceylon has had disastrous effects on the soil. Erosion is widespread and in places very far advanced, and is forcing the development of new ideas about the correct management of estates. In particular, weeds or other forms of ground cover are coming to be regarded as indispensable. Suggestions have even been made to the effect that weeds should be protected by law.

The notoriously intensive agriculture of certain parts of South China where dense populations are almost completely maintained off the produce of the land is in marked contrast to the destitution that reigns in the north-western loess region—the birthplace of Chinese civilization. The wind-blown loess is one of the richest soil materials known, similar to that which has formed the black soils of the Russian steppes. It is also the most easily eroded, when deprived of its natural grass cover. Once erosion has started, it proceeds with great rapidity, and processes of natural revegetation are too slow to keep pace with it. Nevertheless, if erosion can be checked, new soil forms very rapidly from the loess. The gigantic gullies formed by the torrential streams continually undermining the gully walls present some of the most striking pictures known of the power of erosion. The great blocks of loess broken off by the streams are rapidly disintegrated, loading the rivers with silt and causing catastrophic floods. Like the Mississippi, the Yellow River, which drains the loess region, is now largely a 'raised' river, flowing for long stretches above its densely populated plain.

It is improbable that even in the heyday of early Chinese civilization these soils were subjected to what would be regarded by modern standards as 'excessive' exploitation, but long utilization has gradually exhausted them. A vast system of terraces has been built up in the course of time to check the gathering force of erosion, but the terraces themselves are actively eroding, and

no proper provision is made for dealing with the surface water which runs off in drainage courses that later develop into gullies. Terraces may have saved the loess region from total destruction, but they have not stopped erosion. Strip cropping, contour ploughing and other recognized control measures are practically unknown, and owing to the rectangular shape of individual properties and the conservativeness of the people, would be very difficult to introduce. Prof. J. Thorp[1] believes that a radical change from arable farming to animal husbandry offers the most hopeful means of saving the natural grassland loess soils of North-West China, but he recognizes that this would involve a revolution in mode of living which the people would not readily accept. Short of some such revolution, however, the alternative seems to be gradual depopulation of the uplands.

The hundred million inhabitants in the plains are far worse afflicted by the consequences of erosion than the impoverished farmers in the distant highlands where most of the erosion is taking place. Measured in terms of human suffering the periodic floods of the Yellow River are among the greatest recorded catastrophes of history. The Yellow River has always been liable to flood. When men first settled in the plains the region was geologically immature and the great river was still carving an uncertain course to the sea. In time it would have eroded through the plains a channel sufficiently deep and wide to contain all the waters draining into it. Instead, the channel has been choked with silt and the volume of water at flood seasons has been enormously increased, as the absorbent surface soil was removed from the loess hinterland and deposited on the river bed. To control the Yellow River now is a superhuman task. Apart from river control on a hitherto unattempted scale in the plains, it would require land reclamation throughout the immense catchment basin, inhabited by an inert, individualistic people ignorant of the magnitude of the task and indifferent to the larger issues involved. Without soil conservation in the hills, the engineer's work in the plains would be wasted. Without a national renaissance, soil conservation on an adequate scale will not be carried through. Here and there a patch of reclaimed land, successfully protected against erosion under the stimulus

[1]*Geography of the Soils of China*, Nanking, 1936.

of American and European enthusiasm, may show what might be done if enthusiasm were to spread and be maintained for a hundred years—if North China were made to feel itself again young enough to ward off the scourges of flood and famine that afflict its declining years. But there is not much hope; the disease is far advanced and the will to resist it is not there. We look on helplessly while erosion adds another great empire to the list of its victims.

The centre of Chinese civilization has now shifted from its origin in the semi-arid north to the more humid centre and south where land reclamation, both from the engineering and agricultural points of view, is a simpler problem than on the northern loess. Innumerable terraces built to hold back water for rice fields have incidentally accomplished very effective erosion control. In many parts of Central and South China large areas have been completely eroded except for the rice fields which have been saved by terracing. A system of shifting cultivation has evolved in the regions where revegetation occurs quickly. The land is cultivated for from three to fifteen years until it is exhausted, and then left for twenty to fifty or more years until the vegetation has formed new soil. In less luxuriant regions, erosion goes on unchecked, particularly on grazing lands. Reforestation will be necessary to reclaim these lands, but much of them is too far gone to give natural forest reproduction. The farmers, moreover, commonly burn all forest and bush land each year to destroy hiding places of wild beasts or so that the ashes may be washed down to fertilize the rice fields in the valleys.

To the occidental eye the accumulated effects of erosion in the centre and south seem sufficiently alarming, perhaps more so than to the native oriental. Much valuable valley land has been covered with infertile debris, but other land has been enriched by deposition of productive soil material washed down from the uplands. The wealth and self-sufficiency that the Szechwan basin maintained through many stormy times are probably attributable to the fertility of the valley soils constantly renewed by erosion from above, and to the rapidity with which the eroded upland soils are re-formed. The eroding soils, however, are not an everlasting source of fertile alluvium; when they are ex-

hausted, the valley lands will be submerged under gravel and rocks, as has already happened in some places. South and Central China are middle-aged; signs of senility are already apparent, particularly in the Yangtze basin of Central China, but some scope for enthusiastic rejuvenators still exists. It is significant that the protagonists of soil conservation in China have been mainly foreigners. The young West can still see visions of a great and prosperous China equipped with all the implements of modern science, but the old East dreams of a peaceful decline undisturbed by occidental efficiency.

Japan, with its steep valleys covered with loose volcanic soils, liable to torrential storms, and compelled to cultivate intensively every inch of available ground to support its seething population, should by all counts have been washed into the sea long ago. Actually, hardly any erosion is taking place at the present time. The end of Japan as a nation, should the soil be left unprotected under the prevailing conditions, has been foreseen for centuries, and foresters and engineers have developed an exemplary technique in obviating the dangers of erosion. Wherever the vegetative cover is broken on the slopes, immediate disaster is threatened until the vegetation is restored and suitable engineering works have been carried out. It is now a definite part of national policy to maintain watershed areas under forest as the most effective method of controlling flood waters and ensuring the essential food production in the valleys. Since 1897 torrent regulation by forest protection has been compulsory throughout Japan. The threat from erosion comes not so much from the potential loss of soil from the steep mountain slopes as from the deposition of debris on the rice fields in the valleys. Erosion-control work is expensive, often out of all proportion to the value of the land saved, but it is absolutely essential from the national point of view, and for many years estimates for this work have formed an important and regular item in the national budget.

Dr. W. C. Lowdermilk[1] has described how erosion control in Japan 'takes on the nature of a great game of chess. The forest engineer, after studying and mapping his eroding valley, locates and builds one or more check dams. This is his move. He then

[1] *Oriental Engineer*, March 1927.

waits to see what the responses of the natural forces are. The check dam establishes a fixed base level of erosion for the *thalweg* above it. The slipping and sloughing side slopes may after two to five years come to an angle of repose, whereon vegetation will establish itself naturally. More likely this desired result will not come so quickly. The response of the natural forces in their turn determines the forest engineer's next move, which may be another dam or two, or an increase of the height of the former dam, or the construction of side retaining walls. After another pause for observations, the next move is made, and so on until erosion is checkmated. The game takes on a lively interest. The operation of natural forces of sedimentation, plant succession and revegetation must be guided and used to best advantage to keep the costs of this expensive work down to the minimum and to practical proportions.' Experience and necessity have reduced the chances of failure to a minimum. Erosion control has passed from an experimental science into a firmly established art.

CHAPTER VII

The Influence of Soil on Erosion

Soil 'erodibility' is a man-made property. The significance of relative erodibility. Soil 'structure'. The different structures of forest and grassland soils. Agriculture can improve the structure of forest soils but tends to destroy the structure of grassland soils. The gradual improvement of forest soils in Europe compared with their rapid deterioration in America. Soil structure in arid regions. Tropical soil structure. Evanescent tropical soil fertility and shifting cultivation. The formation and maintenance of soil structure as the basis of a stable agriculture. The problem of structure maintenance on grassland and tropical soils.

Considerable importance is nowadays attached to the relative 'erodibilities' of different types of soil. The likelihood that a soil will disappear when it is put to some economic use is, of course, as important a point to the occupier of the land as security is to an investor seeking to put his money to economic use. The user of land has shown at least as great a tendency as a financial speculator to go for quick profits rather than security, but when the user of land speculates he is up against much bigger odds than the financier, and he is a more dangerous fellow to the community at large. The financier knows, or should know, something of the factors making for security of investment; the cultivator has very little knowledge at his disposal about the factors influencing the stability of the soil. Among those factors, 'erodibility' of soil has recently received a great deal of attention without, it must be admitted, as yet contributing very much to our knowledge.

It is not always clearly realized what is involved in the concept of erodibility. Erodibility is not an inherent property of any mature and fertile soil; it is a property induced, most commonly, by human interference. No undisturbed mature soil (with the

possible exception of certain sparsely clad soils in dry regions) exhibits any appreciable erodibility, otherwise it would have disappeared long ago. Natural vegetation and soils form non-eroding systems under the climatic conditions prevailing where they occur, although if a natural vegetation-soil system could be transported bodily to, or artificially reproduced in another climatic region, erosion might take place. Similarly, one type of natural vegetation may perfectly protect soil type A from erosion, but allow erosion to occur to some extent when artificially grown on a contiguous but different soil type B. Afforestation, which has come to be regarded as an almost infallible measure for soil conservation, has failed to achieve its purpose on certain semi-arid grassland soils in South Africa; and a dense grass sod which is the ideal soil preserver on prairie and steppe land has proven only partially effective in checking erosion and flood on Swiss mountain-forest soils. It is too sweeping a statement to say that the natural vegetation type is the only one that will give complete erosion control under the prevailing conditions of soil and climate, but on land newly opened up it is usually the only one that we *know* will afford sufficient protection.

The belief still held in some quarters that erodibility is an inherent soil property capable of quantitative expression has arisen from frequently made observations that of two neighbouring areas similarly situated and cultivated but differing in their soils, one erodes much more readily than the other. What is actually observed in these cases is that one soil type is more erodible than the other *under a particular treatment;* that is, the erodible soil is unsuitable for growing maize, for example, while the non-erodible soil is suitable. The observed erodibility of a soil is, in short, a measure of the unsuitableness of its past and present utilization to the environment—a measure of the extent to which past and present occupiers have misused the land.

Experiments (whether in the field or laboratory) to determine the relative erodibilities of different soil types have to be carried out under strictly comparable conditions as regards the position and covering of the soils. Experiments may be made with soils at a specified angle of slope or with the necessary corrections introduced for slope differences, and kept bare of all vegetation,

in which case the approximate relative erodibilities under fallow are being measured. The erodibility of one soil under different crops or on different slopes (keeping other conditions constant) can also be determined, but in such cases it is the effect on erosion of the variable factor—crop or angle of slope—that is being measured rather than soil erodibility. Experiments have also been made to ascertain to what extent certain inherent soil properties such as texture and chemical composition are related to erodibility. It has been found, for example, that, other things being equal, the granular structure of a virgin steppe soil renders the soil much more resistant to erosion than it is after the granules have been broken down by cultivation; plastic clays, which swell on being wetted and become impermeable, are more liable to erode than non-plastic clays. Under natural conditions, however, 'non-erodible' granular soils are associated with an indigenous vegetation, grass, which by itself would afford insufficient protection to the more powdery soils usually found under forest. In fact, when a forest soil is put down to grass and is thereby deprived of the greater protection given by the forest, the soil reacts by developing, in time and if given the opportunity, a more erosion-resistant granular structure. Similarly, the least plastic (non-erodible) clays are found in the moist tropics where the most erosive rain storms known occur. Soils (in the Caucasus) occurring on gentle slopes have been shown to be more liable to erode than soils occurring on steep slopes when blocks of both are subjected to the action of rain on an equal slope. In general, the more favourable the natural external conditions such as climate, slope and vegetation are to erosion, the more erosion-resistant the soil itself will become. This statement is almost axiomatic, for if a locality is to remain stable, any destructive forces acting upon it must be balanced by an equivalent resistant force.

Provided it is realized, however, that erodibility is a man-made property of soil, the measurement of the property under standard conditions can give much useful information about appropriate methods of land utilization. The most convenient conditions to take as standard, both on account of their easy reproducibility and their tendency to accentuate erosion, are those of bare cultivation. A soil which does not erode appreci-

ably when kept free of vegetation can be utilized for growing almost any crop that it will nourish, whereas a bare soil which erodes easily needs more careful consideration; annual crops that leave the soil bare for long periods, or widely spaced crops like tobacco, maize and cotton are generally unsuitable unless rotated with perennial crops.

By comparing the relative erodibilities of numerous soils under standard but more or less artificial conditions, it has been found possible to ascertain whether any specific properties of soil make for resistance or liability to erosion when the soil is put under cultivation. The property that mainly influences soil erodibility is soil 'structure'—itself a highly complex property since it is compounded of almost every other one possessed by the soil. Nevertheless, structure is a fairly well defined characteristic of soil, and is easy to observe and simple to express, at least qualitatively.

By 'structure' is meant the size and shape of the pieces into which a soil breaks when it is vigorously shaken. Every soil possesses a characteristic structure depending upon the chemical, physical and biological agencies which have been operative during its formation—in short, upon its history. By accepting a somewhat crude definition of structure (like the above) without attempting to analyse closely a most intricate phenomenon, it is possible to distinguish a few outstanding structural types among the innumerable intermediate forms which occur in Nature.

Each of the chief natural plant formations (temperate or tropical forest, steppe, savanna, etc.) is associated with a type of soil exhibiting a particular structure, both in the surface and subsoil. Here we are most concerned with the structure of the surface soil. A coniferous-forest soil has a very weakly developed structure; it tends to break down easily into its constituent particles, but if a vertical section of the soil is examined on the spot, a distinct laminar structure in the upper layers can often be observed, the laminae running parallel with the surface. This structure, or lack of structure, imparts high erodibility to the soil when the forest is cleared; the soil has little natural cohesion, the loose particles are readily dispersed in water and washed

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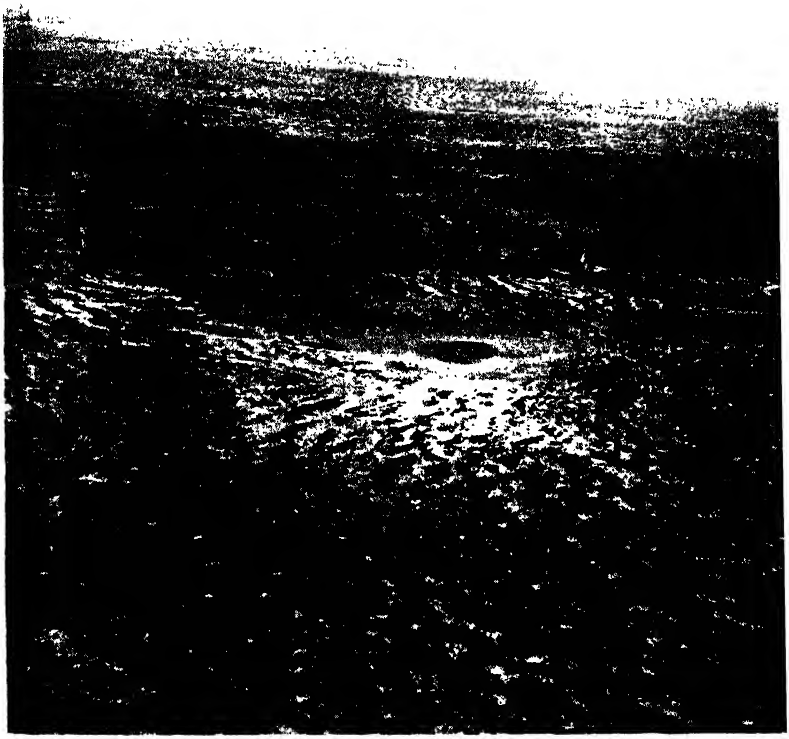
14. British Somaliland. Wind erosion. See page 75.



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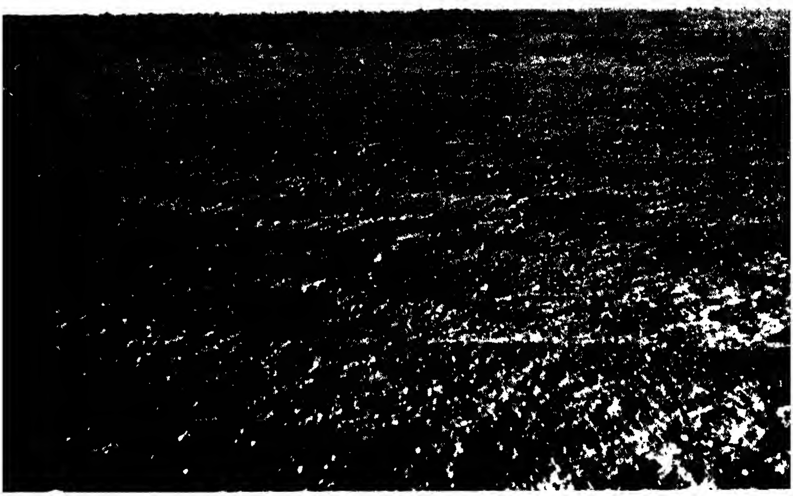

away, and the laminations act as shearing planes facilitating the movement *en masse* of the soil. (The forest, however, affords complete protection against erosion. The tree canopy prevents some rain from reaching the soil at all, and greatly reduces the impact of the rest upon the soil. Far more important is the effect of the forest litter, consisting of dead and decaying branches and needles, which acts like a huge sponge, absorbing and filtering all the water that falls upon it so that only a very slow and harmless stream of clear water percolates into the underlying soil or finds its way into the forest stream. The importance of forest litter has been disastrously proved on many occasions by removing it, while leaving the forest otherwise intact. Removal of litter, for fuel, bedding, or to prepare the land for forest grazing, may produce very rapid erosion and serious flooding. It is worth noting that the characteristic structure of coniferous-forest soils develops largely as a result of the chemical action of the humus in the litter on the mineral soil. The forest humus makes the underlying soil very 'erodible', but at the same time affords perfect protection against erosion.

The typical structure of steppe and prairie soils is quite different from that of coniferous-forest soils. It has been described as 'granular', 'crumbly' and 'nutty', none of which terms is expressive enough, for this structure is the most valuable characteristic that any soil in agricultural use can have. It has, indeed, been described as 'the only structure having any agricultural value at all'.

This rather sweeping statement is to some extent justified since the unconscious object of agricultural cultivation throughout the ages has been to produce a granular structure in the soil. Under a semi-arid continental climate a granular structure occurs naturally, but it is only recently that settled agriculture has been attempted in semi-arid continental regions, and it is

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15 *a*. Australia. Saltbush on a sandy-loam soil, with a tarbrush (*Eremophila glabra*). The collection of litter round the bushes, comprising fallen leaves, loose soil, and the remains of annual plants, can be seen. See page 78. 15 *b*. The final stage in the deterioration of what less than ten years previously was saltbush country, similar to that shown above. See page 78.

turning out to be a much more difficult proposition than might be expected, considering that the ideal agricultural soil was there ready to hand.

A well-developed virgin steppe soil consists of compact granules varying, in different soils, from the size of walnuts to the size of peppercorns, or smaller. The granules impart to the soil the ideal 'tilth' which is the dream of the arable farmer. The soil offers the minimum of resistance to the passage of the plough, and it can be cultivated in either wet or dry weather without destroying the tilth. It is naturally rich in plant food and gives high yields over long periods without any manuring. The separate granules have a strong water-absorbing and water-holding capacity and do not quickly dry out in times of drought, while after heavy rain, when the granules become saturated to capacity with water, any excessive water filters away through the interstices between the granules and water-logging is avoided. A granular soil is thus very largely immune from two of the conditions most conducive to erosion, namely, excessive drying-out and puddling. The granules, moreover, have a characteristically pitted shape which contributes appreciably to their collective resistance to erosion. Unlike the almost structureless coniferous-forest soil, the granular grassland soil does not become 'erodible' immediately the protective vegetation cover is removed.

Nevertheless the natural vegetation—perennial grass—is essential both for the development and maintenance of a granular soil structure. The granules, which impart to the soil as a whole such effective erosion-resisting properties, owe their development to the nature of the humus derived from the grasses and to the multitude of interlacing grass roots which mechanically break the soil up into discrete, compact aggregates.

The soil—rich, deep, homogeneous, porous, retentive of water and easy to cultivate—is the ideal for which farmers have striven in the humid European climate where it does not occur naturally. In the semi-arid climates where it does occur naturally, cultivation measures designed and evolved in the main to encourage soil granulation in humid climates cause the destruction of the granular structure and soil erosion. These different consequences of cultivation—the formation and destruction respectively of a favourable soil structure—will be understood if

we notice the essential features of typical forest and grassland soils (Figs. 21 *a* and *b*). The forest soil consists of (1) a peaty layer of 'raw humus' overlying (2) a greyish-white, structureless or laminated, very acid mineral-soil layer from which most of the plant food has been leached by the action of water charged with acid humic matter, and (3) a compact, less acid subsoil in which the plant food removed from (2) has been deposited. Cultivation mixes these three layers together, incorporates the raw humus with the mineral soil, brings the plant food in the subsoil nearer the surface and reduces the acidity of the topsoil. Cultivation by itself will not produce a stable granular structure in such a forest soil, but it is a step in the right direction. In typical deciduous-forest soils, in which the differentiation into separate layers is only just beginning and a weakly-developed granular structure still exists, cultivation tends to check the normal process of further differentiation and deterioration and to promote structural stability. In Europe the change-over from forest to agricultural soils has been a very gradual process achieved by centuries of cultivation combined with animal husbandry and the liberal use of manures and lime to enrich the soil and reduce its natural acidity. But the resultant soils are not stable under the European climate and if neglected begin to revert to their former condition.

The semi-arid grassland soil presents a very different picture. It exhibits its typical granular structure and is uniform in colour and composition to a considerable depth (sometimes several feet). The subsoil usually appears quite white with calcareous deposits which have originated from lime washed down from the upper soil during wet periods. During the hot and dry summers characteristic of the semi-arid grassland environment some of this lime is sucked up by the ascending current of subsoil moisture so that the surface soil retains sufficient lime to counteract any tendency towards acidity. The living grass roots break up the soil, keeping it well aerated, and help to preserve the granular structure, the dead grass roots humify in, and richly manure, the mineral soil itself, and the dead grass leaves are buried by multitudinous rodents and earthworms which also mix up the soil to great depths and thus keep it thoroughly 'cultivated'. In fact, all the main operations of cultivation and

manuring considered necessary to put the land into good condition for agriculture had been carried out to perfection by Nature long before civilized man appeared on the scene. Note how much this ideal type of soil formation depends, like all other types of soil formation, on the natural flora and fauna. The indigenous grasses are rich in minerals which fertilize the soil when the grasses die, the roots maintain the soil structure, the rodents and worms keep the soil 'fresh' by continual mixing. This mixing, even more than the climate, keeps the topsoil well supplied with lime and ensures a high level of microbiological activity, rapid decomposition of humus, and a steady stream of nutrients available for plant growth. Everything works in perfectly to maintain lasting fertility. The prairie or steppe, with its soil and fauna, comprises the most stable biological community known.

All that is needed to make these soils suitable for agriculture is to plough up the grass and get rid of the rodents and wild animals which might eat up the crops, in other words, to destroy the natural source of manure, the preserver of tilth and the cultivators. The animal cultivators have been replaced by the plough, but seldom has anything recompensed the soil for the loss of its perennial grass cover. It has been unnecessary, uneconomical and impracticable to manure the cultivated prairies and the original humus supply is becoming exhausted. As the humus content falls, the structure weakens and finally breaks down under the plough, the soil pulverizes in dry, and puddles in wet weather, and becomes as 'erodible' as the structureless forest soil deprived of its protective humus cover. Breakdown in structure means a marked deterioration of the soil's physical, chemical and biological properties which make for fertility, and as the soil becomes more erodible it is more difficult to maintain on it an adequate protective cover of vegetation.

Midway in character between the structureless or laminated coniferous-forest soils and the granular grassland soils are the deciduous-forest soils with a more or less unstable granular structure in which faint laminations can sometimes be observed. In moist temperate climates there is a natural tendency for deciduous-forest soils to deteriorate into coniferous-forest soils with loss of the granular structure, but if they are cleared and pro-

perly cultivated and manured the tendency is in the opposite direction of stabilizing the granular structure. This is one reason why serious erosion has not occurred on European, formerly deciduous-forest soils. Apparently the crude cultivation methods used by our forefathers were just what was wanted to turn the scale in the direction of improving the forest soils. On the other hand, the more thorough and efficient methods of clearing the mixed forests and cultivating the soils of eastern America, unaccompanied by the intensive manuring that characterized agricultural development in Europe, accelerated, if it did not actually bring into being, the tendency towards structural deterioration. It is easier to descend than to rise, and the relatively rapid development of the eastern United States involved too sudden a disturbance of natural conditions to be accompanied by an improvement in the soil. Erosion has been very severe in some parts. The eastern American climate, moreover, is more subject to extremes and therefore more erosive than the western European, and probably erosion could only have been avoided by an even more prolonged and gradual process of development than took place in Europe.

As we pass from semi-arid to the really arid conditions of the desert fringe where agriculture can only be carried on under irrigation, the soils become progressively more powdery and, when the desert itself is reached, all trace of soil structure has disappeared, and the loose particles are freely blown about by the wind, causing frequent great sand storms, now rivalled in magnitude by the dust storms of deteriorated semi-arid lands. On the borders of the deserts where only a sparse natural vegetation can exist under a very low rainfall, the soils are to all intents and purposes structureless, but often acquire a certain tenacity by reason of the presence of soluble hygroscopic salts which absorb dew and keep the surface slightly moist. This property of semi-desert soils to absorb any water or water vapour in their neighbourhood both ensures that the maximum amount of moisture possible under the circumstances is at the disposal of the vegetation, and also affords the soils some protection against excessive wind erosion. Even the small amount of rain, however, will in time wash the soluble salts from the surface soil. The washing is much more rapid and complete under artificial irri-

gation. As the salts disappear the soil may acquire a slightly granular structure and become more productive, since an excess of soluble salts is detrimental to plant growth. One of the principal purposes of irrigation, besides supplying water for plant growth, is to remove any *excess* of salts. But as the natural or artificial washing-out of salts continues, the soil structure changes completely, and very much for the worse. When dry, the salt-free soil breaks up into hard, columnar blocks quite impossible to cultivate, and deep cracks appear between the columns; when wetted the soil breaks down to a slimy, almost syrupy consistency, equally impossible to cultivate and very unsuitable for any kind of plant growth (Fig. 21 *c*). This type of soil structure is known as 'black alkali' and is the terror of irrigation farming.

Neither does Nature seem to approve of black alkali. A black alkali soil is about the worst and most intractable kind that can be imagined; it is also the most erodible, indeed it might be said to be the only soil type that is erodible under the conditions of its natural occurrence. Water cannot percolate through black alkali, instead it 'liquefies' the soil, and the resulting syrup flows away bodily until a structureless subsoil layer, charged with salts leached from the black alkali soil, appears on the surface. The cycle—leaching of salts, removal of the de-salinized layer and re-appearance of a saline layer at the surface—goes on continuously and affords a good illustration of how natural erosion removes the exhausted layers of a soil, leaving a fresh layer exposed. This type of erosion is not usually observable but we can deduce its occurrence as a normal phenomenon from the rarity of natural black alkali soils except in closed depressions where soil accumulation rather than denudation is the rule. In the opinion of many investigators, if erosion were not continually going on, black alkali should be much more common in arid regions than saline soils since ample time has elapsed for the salts to be leached out. Actually the reverse is the case. When black alkali is artificially produced by irrigation, erosion does not keep pace with its formation and extensive irrigation areas may be ruined unless adequate measures are taken to prevent the development of black alkali.

Tropical soils have not been as thoroughly studied as tem-

perate soils. They vary greatly, but without such marked differences between types as are found in temperate regions. The most characteristic tropical soil structure is best described as 'cellular'. The soil is rather like a honeycomb, very porous and resistant to erosion. The processes by which this structure is formed are not fully understood, but the intense biological activity prevailing in the soil and vegetation undoubtedly plays an important part in structure development and maintenance. As soon as the natural vegetation is destroyed, the first thing that disappears, with astonishing rapidity, is soil fertility. This is particularly true of tropical forest soils in which nearly all the nutrient material is locked up in the vegetation or kept in continual circulation by the almost instantaneous decomposition of dead plant residues. The mineral soil contains very little plant food. The fertility that produces the most luxuriant plant association in the world is all contained in the vegetation itself; the soil is little more than a foothold for roots and a passage-way through which nutrients are rapidly transferred from the dead to the living plants. Native custom was to clear and cultivate small forest patches for one or two years only and then move on while there was still sufficient fertility left to enable the forest to regenerate itself. When the period of 'shifting cultivation' is prolonged, owing to the pressure of increasing populations for example, fertility soon falls to a level below which natural regeneration will not occur. At the same time, the soil structure breaks down, and the soil is exposed to the exceptionally erosive force of the tropical rains. Erosion-resistant as the structure is, it cannot withstand the direct impact of tropical rain when deprived of the protective intervention of the dense forest canopy. Nature changes quickly in the tropics; whereas it may take twenty or thirty years of faulty land utilization in temperate climates before serious erosion becomes manifest, the same result is achieved in one-tenth of the time in the tropics. It must be admitted that no agricultural system except shifting cultivation has yet been devised that will ensure lasting stability and fertility to tropical forest soils under human management. Shifting cultivation means a nomadic existence for the inhabitants, a low and static standard of living, and requires wars, feuds and epidemics or a strictly enforced policy of birth control

to prevent the population from increasing beyond the limit supportable under the system.

The most successful example of intensive cultivation of tropical forest soils is probably to be found in the Dutch East Indies where erosion has been checked and the soils are still producing good crops of coffee, tobacco, rubber, etc., after forty or more years' continuous cultivation. It is doubtful, however, whether they would have survived, even under the exemplary treatment they have received, had they not been mostly very young soils derived from recent volcanic eruptions, containing reserves of plant food considerably greater than those found in older tropical soils.

We have emphasized the part played by soil structure in the phenomenon of erosion because structure reflects the nature and past history of the environment in which a soil has been formed. It is also a character profoundly affected by human management, the most potent factor in contemporary erosion. Wherever men settle, they inevitably change the nature of the locality; they usurp the soil-forming functions of the natural vegetation and they attempt—blindly at first and more purposefully later on—to change the soil so that it will produce the crops they need rather than the plants for which the soil is naturally best suited. Their operations, continued over long periods, make deep-rooted changes in the soil structure, the direction of the change depending upon the evolution of agriculture and of the community which grows up on the land. If the change is in the direction of increasing soil stability, the community prospers; if it is in the opposite direction, the community declines.

Throughout history the unconscious purpose of cultivation has been to produce a granular soil structure. The cultivators knew little or nothing about soil structure, but those operations which were found to improve tilth and increase fertility were adopted as the basis of agriculture. This basis when once firmly established cannot easily be changed, and the same operations that will convert a poor structure into a good one may, if continued, reverse the process. Irrigation, upon which early civilizations were founded, at first stabilized and fertilized, but finally destroyed, the soil. To-day, in the newly settled natural grasslands, mankind is confronted with the puzzling problem of

what to do with a soil which is physically, chemically and biologically almost perfect for agriculture—a soil which must be changed by human settlement but cannot be improved. Because agriculturists have found their ideal realized in the rich grassland soil they have made no attempt to improve upon it and only occasional attempts to preserve it for posterity. What is to be the objective of grassland agriculture? To retard as much as possible inevitable deterioration and erosion of the soil, to re-build the desolated and eroded regions up to their former fertility, or so to revolutionize agriculture that it is best adapted to some other soil structure than the granular? Whatever the answer, the task promises to be as difficult as any that mankind has undertaken in its perpetual struggle with wild Nature.

The corresponding problem in the tropics—how to preserve a non-erodible soil structure under continuous cultivation—is still more difficult to solve. It is doubtful whether any known method of economic land utilization will produce a stable granular structure in humid tropical soils, or whether any economic crop or economic application of manures can replace the luxuriant wild vegetation as an adequate fertilizer and stabilizer of the land. Artificial fertilizers often produce no positive result on tropical soils. It is possible, however, that entirely new ideas on agriculture and land utilization may some day be conceived, in which the arts of economic cultivation and animal husbandry as we know them will play a very subordinate part. We stress the economic aspect of the problem because an agricultural system —shifting cultivation—is already known which enables men to eke out an existence in the tropics and at the same time preserves the stability of the soil. But it is not a system which anyone would adopt if he intended the product of his land to compete in the markets of the world.

CHAPTER VIII

The Principles of Soil Conservation

Soil conservation is inseparable from good husbandry. 'Vertical' and 'lateral' erosion. Conservation in humid regions. Early conservation by terracing in semi-arid regions. The first principle in conserving semi-arid soils. The evolution of the modern terrace. Contour farming. Mechanical and biological soil conservation. Preventing erosion with plants. Natural soil conservation. Conservation of arable land. The use of weeds. Cover crops. Rotations. Strip-cropping. Individual, communal and regional soil conservation. Floods and flood control. Limitations of engineering control. Soil conservation and floods. River catchments as conservation units.

There is nothing new in the idea of soil conservation. Soil conservation is as old as, and in former times was almost synonymous with, agriculture although nobody used the synonym, which is a recent American invention. Good husbandry consists not only in producing but in continuing to produce good crops. If we wished to distinguish between agriculture and soil conservation, we might define agriculture as cultivation for present and soil conservation as cultivation for future production. Good husbandry combines agriculture and soil conservation.

In humid regions, before the advent of machines and artificial fertilizers, good crops could in general only be obtained by adopting measures like organic manuring, mixed farming and crop rotations which at the same time tended permanently to improve the soil. One type of 'vertical' erosion was very liable to occur, namely, the removal by leaching from the soil of soluble salts and plant nutrients, and many common agricultural operations were designed to prevent this. 'Lateral' erosion did not occur to any serious extent, largely on account of the absence of strong winds, protracted droughts and torrential storms. Nowa-

days the prevention of 'vertical' erosion seems a very simple matter, but it took several centuries for mankind to learn how to counteract the drain on plant foods to which humid soils under cultivation are subjected.

Another way of distinguishing between what we have called 'vertical' and 'lateral' erosion respectively would be to say that the former involves the washing-out of the soluble parts of the soil and the latter mainly the washing (or blowing) away of the insoluble parts. 'Vertical' erosion is always liable to occur in humid regions where the movement of water in the soil is predominantly downwards, but not in arid regions where water is drawn upwards by evaporation. 'Lateral' erosion is very liable to occur on unprotected soils in arid regions because the soil pulverizes and loses its water-absorbing power when it dries out. Both 'vertical' and 'lateral' erosion occurs in the humid tropics owing to the effects of extreme heat and torrential rain.

The natural vegetation counteracts 'vertical' erosion by keeping the soluble plant nutrients in circulation through the plants and back to the surface of the soil when the plants die, and 'lateral' erosion by the soil-binding effect of the plant roots, by the physico-chemical effect of decaying humus on the soil structure, and by mitigating the impact of rain and wind on the soil.

The technical problem of preventing 'vertical' erosion in soils under cultivation has been solved by manuring and by ploughing, harrowing, rolling and so on, with the object of keeping soil moisture near the surface. These cultural practices were adopted because they were found to produce good crops and keep the soil in good heart; the idea that by tilling the soil he was recompensing it for the loss of protection against leaching afforded by the natural vegetation did not enter the farmer's head. He probably recognized the importance of keeping the plough layer moist, but soil chemistry was a closed book to him. Nevertheless he managed to avoid the main dangers of the washing-out of plant nutrients as successfully as if he had possessed the half-knowledge of soil chemistry now available. 'Agriculture' and 'soil conservation' were inseparable and indistinguishable. Technical advances in agriculture may render them less inseparable in the future.

Agriculture, however, had its beginnings in arid lands where precautions against 'vertical' erosion were unnecessary. Indeed, in the very arid plains irrigation was used to induce some 'vertical' erosion and remove the excess of soluble salts as well as to supply water for the crops. On less arid, sloping land the principal cultural operations were evolved to prevent 'lateral' erosion and the run-off of water from the slopes. Early agriculture (in North China, the Philippine Islands and Peru, for example) was particularly notable for the remarkable systems of terraces that it produced. As soon as the land was cultivated it was found necessary to throw up small earth barriers to catch the soil washed down from above, and each year, as more soil came down, the barriers had to be raised and lengthened until in the course of centuries a complete terrace system came into existence. Terracing performed a similar function in early, semi-arid agriculture to that of ploughing and harrowing in later, humid agriculture—it conserved the soil. In one form or another it is the traditional form of cultivation through the semi-arid East.

In South and Central China the primary function of the innumerable terraces on hill slopes has been to hold back water for the rice fields, but at the same time the terraces have accomplished quite effective erosion control. That it was the need for irrigation water rather than a desire to save the soil that impelled the Southern and Central Chinese to undertake these tremendous engineering feats is shown by the traditional way they cultivated—and still cultivate—unirrigated rice by planting in rows running up and down slopes, causing rapid erosion and abandonment of the fields after a few years. These people do not appear to have been really 'erosion-conscious'. Their object in terracing was to save the scanty water supply and keep it in the top layer of the soil. Where they could attain their object without terracing, they gave little attention to protecting the actual soil against erosion.

Soil conservation, in the sense of counteracting the destructive effect of rain on cultivated soil, has been an essential, albeit sometimes incidental, feature of all successful agricultural systems. It was none the less essential for being incidental. As long as men, guided by intuition and with crude implements helping

the work of their hands, treated the soil to their best advantage, soil conservation looked after itself. Only since science has shown the way to multiply the natural output from the land has soil conservation come to be regarded as something almost distinct from normal agriculture. Unfortunately for the soil, it was found that the agricultural systems that prevented 'vertical' erosion on humid land could be adopted to produce large profits on semi-arid land where 'vertical' erosion was practically non-existent. Thus the soil-conservation side of agriculture was gradually eliminated as redundant, and fat profits continued to be made from the soil by pure exploitation until there were no more profits left.

The principles of soil conservation that will have to be reintroduced into modern semi-arid agriculture are fundamentally the same as those which evolved naturally as part of the agriculture of the ancient East, but profoundly modified in detail to suit the changed conditions of the age. The first object of soil-conservation measures on semi-arid land is to make the best use of rain. When this has been achieved, the problem of preventing 'lateral' erosion by either water or wind is already half solved. In the humid tropics the matter is complicated by the fact that both 'vertical' and 'lateral' erosion is threatened, and the experience gained in soil conservation in both humid-temperate and arid-temperate regions needs to be taken into account. But wherever the soil-conservation side of agriculture has been neglected for the sake of economic opportunity, its reintroduction will mean that somebody must suffer a reduction in immediate profit or incur a greater loss than would otherwise have been necessary. That is the rub. The fundamentals of soil conservation on semi-arid land were worked out by the ancients; they are simplicity itself on paper, but cause revolutions now that circumstances are compelling their re-introduction after a highly profitable period of neglect.

The first principle underlying all measures for controlling water erosion on semi-arid land is to reduce the velocity and amount of run-off—especially the velocity, the amount usually being reduced at the same time, since the lower the velocity the greater chance the water has of being absorbed by the soil.

One of the most common methods of reducing run-off velocity

is to break a slope by terracing. Damming water courses and 'listing' are other purely mechanical ways of checking run-off, bolstering up the weakened fabric of the soil and cementing it anew with moisture. As water flows down a slope, it accelerates under the force of gravity, its erosive power increasing as the square of its velocity (i.e. doubling the velocity quadruples the erosive power). By throwing a terrace or dam across the direction of flow, run-off water is held up, soil carried in suspension is deposited, and by skilful management any excess of water not absorbed by the soil may be turned to some useful purpose such as irrigating lower-lying land or watering stock. At worst, the accumulated water debouches over the terrace or bank, possibly destroying it in the process, and continues down the slope with lower velocity and erosive power than if its progress had been unimpeded. Terracing is the oldest known method of stopping erosion, but the flat 'bench' terraces (like those illustrated in Fig. 25) of former times have little applicability to large-scale mechanized farming. The broad-based, contour terrace, described in Chapter IX, has been evolved from the bench terrace to suit modern conditions, and it is noteworthy that its evolution has been the work of practical farmers far more than of trained scientists. It is therefore more likely to be a natural growth. At some future time the broad-based terrace may be regarded as the most enduring characteristic of twentieth-century civilization, and men may marvel at the painstaking ingenuity with which a primitive people tilled the soil and became masters of the elements.

The modern terrace does not seriously interfere with the operations of mechanized farming; such interference as it causes is mainly to the good, since it prevents destructive cultivation like ploughing up and down slopes from being used. Terrace design is being further improved with the object of utilizing in the most efficient way the water which the terraces catch. Very frequently the water can all be absorbed into the soil and utilized by crops growing on the spot. Where complete absorption is impracticable, provision can be made for irrigating low-lying land with the excess of water, for distributing and catching the water on a series of lower terraces, or for conducting it into natural drainage channels where it can do no harm. Similar

provision has to be made to deal with the excess of water flowing over and round dams built across gullies, for run-off is a perpetual source of danger until it reaches its destination in the sea. The design of terraces and dams is becoming a specialized engineering job in which local characteristics of climate, topography, geology, soils and vegetation have to be taken into account.

Since the object of terraces is to check as far as possible the flow of run-off under gravity, they are most effective when built on one level, i.e. following the contours of the land. A picture of a field terraced on the contour looks rather like an orographical map, in which the contour lines twist and turn and double back on themselves according to the lie of the land. A contour-terrace system on an uneven slope has an almost grotesque appearance, very different from the straight-furrowed field that used to be the ploughman's pride. Ploughing along the contour—an operation that may require considerable skill—has much the same effect as contour terracing, each furrow acting as a diminutive, temporary terrace. When, on the other hand, the plough runs *across* the contour (up and down a slope), each furrow becomes a storm drain for run-off and may develop into a permanent, eroding gully. Lines of contour have acquired great significance in the cultivation of semi-arid land. The phrase 'contour farming' has been coined to describe modern systems in which cultural operations are carried out as far as possible on natural levels, instead of on artificial levels as in the old flat-bench tertace systems. The difference is that in one system the farmer adapts his operations to the lie of his land, and in the other modifies the lie of the land to suit his operations.

Nowadays, however, a diminishing importance is being attached to the part the engineer can play in soil conservation. An outstanding feature of the modern outlook on soil conservation is the emphasis laid on the superior value of biological, as compared with mechanical, erosion control. If the soil is performing its natural biological functions of feeding and *being fed by* living organisms, it will not in general erode seriously. Biological soil conservation is not new; indeed the cultural operations that were evolved to keep humid soils 'in good heart' may be regarded as biological measures of soil conservation. They im-

proved soil structure, aeration and drainage and, by enabling the soil to support a rich flora and fauna (microscopic as well as macroscopic), kept the plant nutrients circulating in the surface layers. The same operations are wasted for this purpose on semi-arid soils. Soil structure can be preserved, within limits, by the use of organic manures (of which there are seldom enough to go round) but the traditional methods of cultivation tend to destroy the structure, and consequently the biological activity, of semi-arid soils. Great attention is therefore being given to the possibilities of utilizing plants not solely as economic crops but also in their natural role as protectors of soil fertility. Soil conservation is joining forces with purely economic agriculture to produce good husbandry.

Biological control of erosion by means of plants may be likened to treating a disease by dieting or to maintaining good health by temperate living, and mechanical control to a cure by operation. In advanced cases where the whole body politic is infected with the disease and its complications, the surgeon's knife may have to work drastically; in less advanced cases the general practitioner may be able to heal the wounds in the land before they fester and spread. Immunity, however, is better than either prevention or cure, and can usually be obtained by living temperately off the land. But temperate living is not easy to sustain when times are bad, and very difficult to enforce in an unorganized industry like agriculture. In this sense 'temperate living' means growing plants primarily to feed the soil. Almost any plant cover will do this to some extent; the art of soil conservation by vegetation consists in finding the best plants and the most appropriate method of cultivating them so as to secure the maximum soil protection compatible with the economic maintenance of the cultivator.

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16 *a*. Australia. Boundary fence between two blocks in the north-east. The paddock in the foreground has suffered erosion following the destruction of the saltbush cover by stock. See pages 77-81. 16 *b*. Bullock bush (*Heterodendron*) in a drifting paddock. Some eighteen inches to two feet of soil appear to have been blown from the bases of the trunks. The tree on the left shows a characteristic root sucker. See pages 77-81.

As we have seen in the last chapter, the structure of the indigenous plant cover is usually related to that of the soil in such a way that the vegetation and soil together form a natural, non-eroding system. The indigenous wild vegetation can also be relied upon to succeed in its natural habitat without human assistance and is therefore ideal from the soil-conservation standpoint. Where the indigenous vegetation can be maintained indefinitely and at the same time be utilized economically, the problem of soil conservation ceases to exist. This is the object of sustained-yield forestry and controlled grazing. Sustained-yield forestry consists in managing a forest so that only as much wood is cut every season as is contained in the trees that would have died in the natural course of events; or, if more is cut, tree growth must be correspondingly stimulated. In this way the structure of the forest is not materially changed by utilization. Controlled grazing involves management so that the floral composition of the pastures does not change, or at least does not deteriorate. Many natural grasslands carry, in the wild state, an indigenous grazing fauna, and the domesticated animals introduced by men must be regulated to have much the same effect on the flora as the wild fauna had. Difficulties in applying these principles arise when there is an insatiable world demand for wood and meat, and sustained-yield forestry and controlled grazing run counter to world economic forces.

Civilization, moreover, requires a greater diversity of produce than can be supplied by forests and pastures. Where arable farming is concerned, soil conservation with crops consists in cultivating in such a way that as much of the soil as is practicable is protected by plants for as long as possible. Hence the bad name that widely spaced, clean-tilled crops like cotton, maize and tobacco have gained from the erosion that so frequently accompanies their continuous culture. With such crops, some measure of mechanical soil conservation is often unavoidable. With some clean-tilled crops the soil can be adequately protected by allowing weeds to grow. Weedy land is no longer

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17. India. Etawah, United Provinces. Afforestation of ravine lands. Soil preparation on moderate slopes with ridges and ditches ready for sowing. See page 124.

necessarily a sign of bad farming. The rubber tree, whose natural habitat is the tropical rain forest, grows just as well on weedy as on clean land. For many years it has been the custom in the Dutch East Indies not to trouble much about weed growth in rubber plantations, and the same custom is now being adopted for soil-conservation purposes in Malaya and Ceylon. Provided a few obnoxious species are suppressed, rubber can hold its own against the indigenous weed flora and together with the weeds will supply all the protection the soil needs against erosion. Tea planters in Ceylon are likewise beginning to put a conservation value on weeds, although the matter is not quite as simple as with rubber. Tea is more exacting than rubber, and cannot stand up to weed competition so well. Weeds, moreover, utilize moisture and plant food required for the tea crop and, unless controlled, are liable to reproduce jungle conditions in a very short time. A new system of 'selective weeding', in which just as many weeds as the tea plants can tolerate are allowed to grow, is being evolved to cope with the disastrous erosion which has accompanied clean weeding in Ceylon. On most estates complete protection cannot be secured merely by regulating the vegetation, and some form of terracing is also necessary.

Instead of protecting the bare spaces between crop plants with weeds of no economic value, useful cover crops can often be grown with great advantage. Leguminous cover crops which fix atmospheric nitrogen and thereby actually enrich the soil are especially valuable. Cover crops of course may compete with the main crop in the same way as weeds, but on the other hand, if judiciously selected, may actually increase the vitality of the main crop, since many plants grow better in mixed than in pure culture. If the cover crop is subsequently ploughed back as a green manure the soil is improved when the added organic matter humifies and also recovers all the plant nutrients absorbed by the cover crop and, if the crop is leguminous, an extra quantity of nitrogen fixed from the air. Needless to say, a good cover crop will not grow—as weeds will—without the expenditure of money and work. Among the more popular advantages of pioneer farming, which has to be superseded by conservative farming on eroding land, are that much money

need not be buried in soil improvements and that the farmer can, if he adopts monoculture, escape from his arduous duties during winter. The farmer often clings to these advantages even at the cost of the greater ultimate benefits he would derive from conservative farming.

The main purpose—for soil conservation—of weeds and cover crops is to protect the soil from the direct impact of rain and wind, although other advantages also accrue. The same purpose is fulfilled by suitable crop rotations. In the highly farmed European countries crop rotations allow intensive mixed farming to be carried on with a great diversity of produce, they eliminate the uneconomic fallow, facilitate weed and pest control, and help to keep hired labour employed throughout the year. These advantages have a much lower value in extensive pioneer farming, and crop rotations fell into immediate disuse when the new countries were opened up. The ordinary European rotation (e.g. the Norfolk four-course—winter cereal, roots, spring cereal, clover) has, moreover, little value for soil conservation in semi-arid regions where the aim should be to keep the soil well covered for as long as possible. The essence of soil-conserving rotations is to alternate arable crops with dense sod crops; the function of the sod being not only to protect against rain and wind, but also to build up the soil structure and make the soil more resistant to erosion when next it comes under the plough. It may be noted that soil-conserving rotations including sod crops aim in effect at preserving under cultivation some of the more desirable characteristics of natural grassland soils.

Numerous investigations, particularly in Russia, have shown that perennial grasses will produce a stable soil structure, with a great increase in permeability persisting for some years after subsequent ploughing, in nearly all types of soil. On the eroding grain-producing steppes of Russia, six-course rotations including at least two years under clover sod are recommended. The clover seems to be the main cause of the increased resistance to erosion, but the improved soil conditions are transitory and disappear in the course of the complete rotation. In the moister forest-steppe regions an erosion-resisting soil structure can be maintained by adopting a four-course rotation including two

years under perennial grasses adequately fertilized to ensure rapid and luxuriant growth.

The effect of rotation of crops on checking erosion is often out of all proportion to the mean effect of the separate crops. Miller[1] gives the following figures showing the average annual erosion and run-off under different cultivation.

TABLE I

AVERAGE OF 14 YEARS' MEASUREMENTS OF RUN-OFF AND EROSION, MISSOURI EXPERIMENT STATION, COLUMBIA

(Soil type—Shelby Loam. Length of slope, 90·75 feet. Degree of slope, 3·68 per cent)

Cropping system or cultural treatment	Average annual erosion per acre in tons	Percentage of total rainfall running off the land
Bare, cultivated, no crop	41·0	30
Continuous corn	19·7	29
Continuous wheat	10·1	23
Rotation—corn, wheat, clover	2·7	14
Continuous bluegrass	0·3	12

The mean erosion from the continuous corn, wheat and bluegrass plots is about 10 tons, compared with 2·7 tons from the rotated plot. Apart from the longer time the soil is covered by the rotation, Miller ascribed the good effect to the organic matter added by the clover, which improves soil structure and water-holding capacity. It is not to be expected that any rotation including arable crops will equal a continuous grass cover in its soil-protecting influence, but even a little grass or clover in the rotation effects a big saving of soil and water. The science of soil-conserving rotations is still in its infancy and will develop rapidly as experience accumulates of the influence of different crops on soil structure and biology.

[1] *Cropping Systems in relation to Erosion Control*, by M. F. Miller. Missouri Agricultural Experiment Station, Bulletin 366, 1936.

18. India. Abandoned cultivated land where previously there were well-matted (contour ridged) fields. See pages 86-88.

STRIP-CROPPING

The biological control of erosion by crop rotation can be reinforced with mechanical control by adopting a system of 'strip-cropping'—i.e. sowing close-growing and clean-tilled crops in alternate, narrow strips laid out across a slope on contour lines. The close-growing crops absorb all the rain that falls on them and prevent erosion, and at the same time catch any soil and water carried down from the clean-tilled strip above. The close-crop strips act in effect like contour terraces, checking the velocity of run-off water from the clean-tilled strips. By adopting crop rotations on the strips, so that every strip is sown in turn with a close-growing crop like grass, erosion and run-off can be reduced to a minimum and a stable soil structure can be built up and maintained over the entire slope. Strip-cropping, by forming a series of windbreaks, is equally effective in preventing soil drifting on level plains. It is one of the most hopeful new developments in soil conservation. In 1937 over two million acres were 'strip-cropped' against erosion in the United States.

Terracing, gully-damming and listing; regulated forestry and grazing, revegetation, selective weeding, cover cropping, mixed farming and crop rotations, strip-cropping—these are the basic measures now being adopted and developed to conserve eroding soil. The first three are mechanical, the rest are mainly biological, in operation. By mechanical means men attempt to mould their environment to suit their requirements, by biological means they attempt the more complex and more fruitful task of adapting their requirements to the unchangeable features of their environment. The soil-conservation movement, steadily gathering momentum throughout the New World, represents an early stage in civilization's adaptation to new environments. The conservation measures so far attempted are notable for their crudity and simplicity. A little elementary instruction enables anybody to apply them to his land; but when everybody ceases to be an exploiter and becomes a conserver of soil, the foundations of a society that has established itself on exploitation are shaken. The problem of soil conservation is not solved merely by discovering the simple practices that

19. India. Fifty feet of erosion exposes ancient well built before Sikh rule by Jaswal Rajahs. See pages 86-88.

will minimize erosion; when the right practices have been discovered, or—more correctly—when the need for adopting the practices has been recognized, the great task is to procure their general application.

The adoption of soil-conservation practices as the basis of land utilization is a trend in social evolution whose direction can be guided but not determined by organized, conscious effort. The modern soil-conservation movement is of such recent date that most countries are still at the stage where their main concern is to induce individuals to save the land they occupy. The next stage, when the interdependence of adjoining bits of land becomes apparent, is to substitute communal for individual soil conservation. To take a simple instance, the security of every part of a hill slope depends upon the use made of the other parts; it is useless to conserve the lower parts if the land is to be submerged under flood and soil from above, or to conserve the upper parts if they are to be eaten into by gullies working their way up from below. Where a river has run amok as a result of erosion, every dweller in the valley, in country and town, is affected by the use made of the land which the river drains.

A human community, like a plant community, depends for its continued existence upon a sure and regulated water supply. The flow of a main river, along whose banks great towns are built, depends upon the flow of its tributaries, whose flow in turn depends upon the use or misuse of the forests and fields which feed them. Thus regionally organized soil conservation becomes the vital concern of the whole community inhabiting a river catchment basin. Since water conservation (in semi-arid regions) is very closely related to, and inseparable from, soil conservation a river catchment basin comprising a complete natural drainage system is the ideal regional unit for conservation work. In practice, an entire catchment basin is seldom a feasible unit; it may be too large for effective control of land utilization, and it may be cut into by political frontiers and economic lines of communication which have no relation to geographical boundaries. The artificial nature of State and county boundaries in America and the laws which have to be respected regarding them are as serious obstacles to the execution of a scientifically planned scheme of regional con-

servation as is the inertia of farmers or the distribution of the rainfall.

Consequently the regional soil-conservation units that are evolving in the United States—the only country yet where conservation has become a community concern—have neither political, economic nor geographical boundaries. In the first place, their boundaries have been set by expediency, later they may be realigned under the influence of geographical and political factors. In the United States, community soil conservation has reached the stage where a number of farmers will agree among themselves to follow a definite scheme of land utilization and to take the necessary precautions on their own land to secure soil stability throughout their district. A more ambitious community conservation project, embracing the whole catchment area of the Tennessee River,[1] is being worked with considerable success but is encountering sufficient political and economic difficulties to show that the time is not yet ripe for organizing community conservation projects except in localized areas.

The need for far-reaching community action to conserve the land is most apparent when floods become chronic as a result of widespread erosion in a catchment area. Then urban dwellers are brought face to face with erosion's most spectacular disaster, when the accumulated waste of water and soil from distant cultivated fields and cut-over forests threatens their lives, property and livelihoods. When a densely populated city is threatened by flood there can be no question of whether protection should be undertaken by separate individuals or by the community, but the protective dams, levees and detention basins built by cities or valley communities cannot generally be classed as *soil*-conservation works. The city engineer, engaged on flood protection, is not directly concerned with removing the cause of the flood; his object is to regulate the volume and flow of the river within safe bounds, and to utilize the water to the greatest advantage of the city he serves.

Every community, great or small, in a valley subject to flooding must protect itself. The measures necessary to save one community frequently react harmfully on another. The only way to

[1] See Chapter XIX.

avoid siltation is to keep the muddy waters moving, and the faster they move the less silt is deposited and the more it is collected by the river. The simplest way to dispose of a flood wave is to confine it to the normal river channel with the help of embankments or levees and send it downstream with its silt load and destructive force increased by its greater velocity. Such disposal is clearly impracticable when the valley downstream is densely populated. It thus becomes necessary to regard the valley as an indivisible unit and to dissipate or control the flood waters and silt so that unavoidable damage is fairly shared by the whole population. When it is remembered that every check to the flood stream means deposition of silt, and every deposition of silt means reduced efficiency of flood-control structures like levees and reservoirs, it will be realized that flood control by engineering tends not only to become more complex as the flood plain is developed, but also less effective the more control is applied. The ultimate and permanent control of floods can only be effected in the forests and fields where they originate. The cities of the plains can obtain their food from other regions, but their water comes in surfeit or sufficiency according to the use made of the near and distant hills and valley slopes which feed their particular river system. Every part of an eroded catchment area has a vital interest in what is being done in other parts.

It is, however, not often necessary to administer a complete catchment area as a soil-conservation unit; still less often is it possible. Nowadays political and administrative boundaries are often fixed without regard to natural geographical features, and their arbitrary location may lead to great administrative difficulties when the need arises for a common policy of soil conservation throughout a geographical region. The catchment areas of the Mississippi and Yellow Rivers, both of which are subject to frequent catastrophic floods in their valleys as a consequence of erosion around their headwaters, are outstanding instances where unified flood and erosion control throughout the catchment areas is desirable, but the administrative difficulties of adequately controlling land utilization over such vast regions make any considered plan impracticable. The most ambitious scheme yet attempted with any chance of success is the conservation project in the catchment area of the Tennessee River (a

tributary of the Ohio River in the Mississippi system), but even there the difficulties of securing unified control of land utilization in seven separate States threaten to wreck the whole scheme.

The development of regional soil conservation—i.e. the organization of complete natural regions so as to ensure the lasting stability of the land—is inevitable where erosion is liable to occur, but development must be a gradual process. Conservation schemes covering small districts are already in operation in parts of the United States. As experience of their working accumulates they will be modified to dovetail into other district schemes until they merge insensibly into a loose regional organization. One can envisage the slow building up of a complex society based upon the natural interdependence of town and country, and of the hills and valleys and plains that give rise to a great river and determine its flow. In regions where erosion occurs the water supply tends to be irregular or deficient and erosion intensifies its irregularity. The existence of organized society in these regions depends, before anything else, upon the flow of the rivers, which is determined and can be regulated by the use made of the land.

CHAPTER IX

The Development of a Conservation Agronomy

New technique in arable cultivation. U.S.A. taken as an example. Planning the reorganization of a farm. Application of ecological principles. Relative merits of crops, grassland and forests, as protective canopy or cover. Treatment of land according to degree and length of slope. Slope classes recognized bv the U.S. Soil Conservation Service. Conservation agronomy. Crop rotation. Contour cultivation and planting. Strip-cropping. Rotation between strips. Terraces for steeper slopes. The modern broad base ridge terraces. Location of terraces. The Mangum and Nichols terraces. Terrace outlets. The adaptation of technique to other countries. Plantation crops. Rubber in Malaya and Ceylon. Coffee in Java and Tanganyika. Vegetable cultivation. Orchards.

The revolution in cultivation technique which is taking place slowly in the more advanced countries affected by erosion involves radical changes in the selection of land for different types of cultures, and in the methods of cultivation, sowing and arrangement of crops. New methods are gradually being developed for the treatment of arable land, orchards, plantation crops, vegetables, pastures, range and forest, and for the special problem of the cultivation of crops under semi-arid conditions. Pastures, range, forest and semi-arid lands are discussed in subsequent chapters. Attention will now be devoted to arable land and to the other special types of cultures mentioned above.

As the United States is one of the most advanced countries in the development of a conservation agronomy, we shall devote some space to a consideration of the various agronomical practices which are being recommended by the Soil Conservation

Service, and which are being gradually adopted on an ever-increasing scale among the farming community, particularly on the soil conservation demonstration projects, and the newly constituted districts. Many of the conservation practices were adopted some years ago and have since been confirmed by the experiments laid down on the Soil Conservation Experiment Stations; others have been changed to conform with the results from these Stations.

In planning the reorganization of a farm with the object of controlling erosion and conserving moisture, a number of points must be borne in mind. These may be classed as (1) physical characteristics of the land, and (2) economic influences. The physical points include steepness and length of slopes, degree of erosion, erodibility of the soil and the vegetative cover. The economic factors include livestock units, feed requirements, crop use, marketability of crops, land value in comparison with the structural costs of control measures, and the permanency of the measures recommended. The best type of land-use is decided upon by all specialists concerned, such as agronomists, foresters, engineers and conservationists. The farm and not individual fields must be the unit, although this does not remove the problems arising from the attempt which has been made in the United States to fit square farming into a round country (see Chapter III).

There is in all countries a growing tendency to adopt the less extreme and cheaper methods and a greater realization of the amount of healing which Nature herself can achieve if allowed to act without interference by man or beast. So many of the erosion losses have been caused through mismanagement of cultivated land and overgrazing of grassland that much can be done in the direction of conservation by the adoption of more reasonable types of agriculture in place of the soil 'mining' characteristic of the pioneer agriculture on new and fertile soils, and of the gross overstocking of hitherto untouched grassland areas. There are, of course, many other areas where, even with the adoption of good cultural practices, the unusual climatic or soil conditions make it necessary to introduce some special conservation practice before cropping or grazing can be carried on with the minimum of soil loss and water run-off.

The importance of the application of ecological principles to erosion control is frequently stressed. In this 'vegetative engineering' or 'ecological engineering', the fundamental considerations are the restriction of cultivation to flat or vegetative covers managed and directed through controlled ecological successions. The present problem in most parts of the world affected by erosion is to adopt emergency steps to arrest the damage caused by the accelerated erosion, but the final aim should be the elaboration of permanent methods of erosion-control agriculture and ecological engineering.

Before describing the methods of conservation used or recommended for cultivated land in the United States it is necessary to discuss the relative merits of different crops, types of grassland and forest as a canopy or a cover to protect the soil from the eroding agents, rain and wind.

When rain falls upon a forest, the force of the drops falling from the leaves is broken by the litter on the forest floor, which prevents the raindrops from beating soil particles into suspension, thereby clogging the pores and other openings in the soil and reducing or preventing percolation. The water that is permitted to enter the soil in a normal forest through infiltration replenishes the ground water supply, which feeds springs, wells and streams. Deforestation causes a reduction in infiltration by exposing the soil surface to the impact of the rain and ultimately leads to a marked fall in the level of ground water, with its attendant dangers. As an extreme example may be quoted the serious reduction in the base level of the Jumna River in the United Provinces in India, where flooding and scouring has lowered its bed at Etawah sixty feet in the last five centuries, with a corresponding fall in the level of the springs level. The cold-weather level of the river is often 120–200 feet below the surrounding country. The effect of this upon the ground-water supplies is obvious.

Forest soil is loose and open, with a capacity for absorbing and holding considerable amounts of water. This reappears gradually as springs or passes directly into streams; in this way

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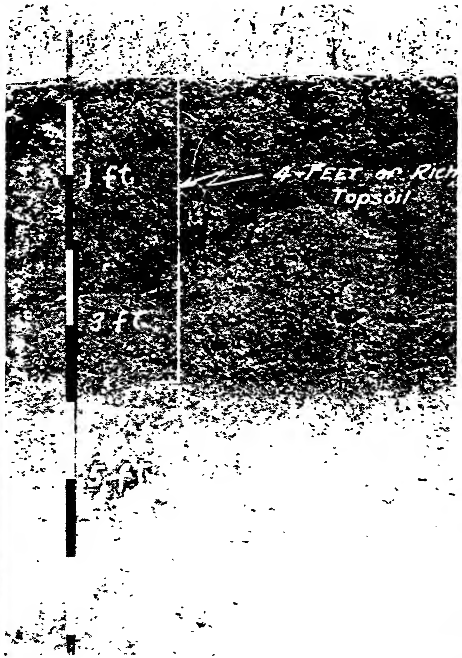
20 *a.* Java. Terrace cultivation of millet. See page 136. 20 *b.* Java. Rice cultivation in terraces. See page 136.

(a)



(b)

(c)

forest vegetation reduces the peaks of high water and tends to maintain the flow at a moderate level between the periods of excessive rainfall. Any water that does run off from forest areas is clear and carries little sediment to increase the eroding powers of the water or to be deposited in reservoirs.

Pastures and meadows have an advantage over forests in being an economic proposition which can be recommended to farmers whose cultivated land is eroding badly, but who may not be able to afford to retire any but their very steep slopes to trees. The soil-conservation qualities of a pasture depend upon its treatment and management. A sward in good condition, well manured and of superior botanical composition, is very little inferior to forest growth in controlling soil loss and run-off. The raindrops are again prevented from beating on the soil surface, the leaves lead the water into the absorptive soil, and the grass roots bind the soil in such a way that the excess water from torrential downpours flows off, carrying little sediment. Run-down pastures and range lands, composed of isolated plants, stemmy annual grasses and weeds, with little legume content to form a close bottom to the sward, are inferior for soil and water conservation. The rain beats upon the bare spaces between the plants, seals up the soil pores and runs off, carrying with it some soil in suspension. As the process advances, the little streams passing between the plants acquire increased volume and eroding power, thereby initiating rill and ultimately gully erosion.

Little inferior to grass and clover swards in controlling excessive soil loss, if not in reducing run-off, are the numerous close-growing crops sown on cultivated land. These include hay

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21. Soil types illustrating three contrasting types of soil structure. 21 *a*. An acid, coniferous-forest soil with a bleached, almost structureless layer, showing faint lamination to the left of the measuring rod. 21 *b*. A neutral, prairie soil with a well-developed granular structure imparting an excellent tilth to the soil. 21 *c*. An alkali soil, formed by irrigating a saline soil, and showing the characteristic hard columnar blocks and an efflorescence of salts washed down into the subsoil from the surface. See pages 99-102.

grasses grown alone or in combination with a clover; also lespedeza, lucerne or alfalfa, and annual hay crops, cereals, legumes or pulses.

The crops which permit most damage from erosion are the clean-cultivated ones, which are planted wide apart and cleaned from weed growth at regular intervals during the year. These include cotton, maize (corn), tobacco, potatoes, sorghums, millets, soy-beans and beans, although some are fairly erosion-resistant when sown in narrow drills. The chief trouble with these crops is that they are in most cases those which have been grown under continuous cropping for periods of from ten to fifty years, without the use of any type of rotation which would return organic matter or grass root fibre to the soil, or of a cover crop to protect the soil during the critical periods of the year, when rains or winds are actively operating as eroding factors.

The relation of degree and length of slope must receive consideration when decisions are being made regarding the retirement of the steeper slopes from cultivation. Although this may do much to reduce run-off and soil wash and to control floods, it frequently happens that the individual farmer is not in a sufficiently strong economic position to afford to retire his steeper lands from tillage and devote them to less remunerative forest or grass crops. To meet this problem a special line of research is being developed in the United States, based upon the system of *Bergcultuur* developed in the Netherlands East Indies. This 'hill culture' research in the United States aims at the production of speciality products from superior selections of trees, shrubs and herbaceous plants, thereby providing the farmer with an economic return from land which he is obliged to retire to woodland (see Chapter XII). An important function of farm woodlands from the conservationist's point of view is that they provide cover for the wild-life 'crop', which should be encouraged wherever possible.

The U.S. Soil Conservation Service classifies slopes on the basis of their optimum utilization in a comprehensive erosion-control plan. Obviously, on this basis, the determination of slope-class requires consideration of the general nature of the region. The gradient range within any one class may vary

considerably from region to region. Four classes are distinguished:

Class A. Slopes requiring no particular erosion-control measures, other than proper crop rotation.
Class B. Require erosion control when clean-tilled crops are included in the rotation.
Class C. Unsuitable for clean-tilled crops; recommended for pasture, hay, or other close-growing crops.
Class D. Should be left or put under forest or pasture, depending on the original vegetation.

Thus, the steepest slopes on the farm are planted to trees. The Soil Conservation Service then recommends that the slopes in the next grade of steepness should be retired to permanent pasture, with fertility treatment to promote the development of a superior vegetative cover and controlled grazing to maintain a close erosion-resistant type of sward. It can then be decided how the cultivated land on the farm may be used to the best advantage, both as regards economic return and erosion control.

As this new distribution of woodland, pasture and cultivated land is arranged according to the contour of the land, the old square field system of farming the curves and slopes of the farm has to be abandoned. Hedgerows, fences and other field divisions running up and down the slope are removed, as they tend to favour the flow of eroding waters in a certain direction; their removal further facilitates cultivation of the slopes on the contour. It is thus probable that a great change will gradually take place in the appearance of the landscape in the United States and other countries where erosion control is to become a primary concern of the farmer.

The agronomical methods of value in the conservation of soil and water include rotation of crops, green manuring, contour cultivation and planting, strip cropping and terracing, combined with such methods of water conservation, water spreading and gully control as local conditions may require. Provided that the above-mentioned distribution of woodland, pasture and cultivated land has been adopted, crop rotation and contour farming may provide sufficient control. Where steeper slopes have to be cultivated, the crops of the locality in question are

rotated in strips, and where particular difficulty is experienced in guiding excess water off the land, terraces are constructed.

The absence of crop rotation has been a characteristic feature of the agricultural systems adopted in many areas where virgin soils have been broken up for the first time, particularly in the United States. These soils continued to give good yields for many years under continuous cropping, according to the amount of fertility stored in them. But the fertility must inevitably fall, the soil crumb structure breaks down, the grass fibre disappears and the soil is at the mercy of the elements. With continuous as distinct from shifting cultivation a rotation of crops must be introduced wherever possible, utilizing the staple crop of the region in rotation with a grass or leguminous crop, with possibly a cereal as a third constituent. The types of rotation vary widely; for example, in the United States, the principle of the alternation of intertilled and grass or leguminous crops with small grains (cereals) is varied for different humid parts of the country. In New England, hay and pasture must necessarily occupy most of the years of the rotation; in the Corn Belt, two and possibly three crops of corn can be grown in succession on many farms, in rotation with clover and small grains; in the south, cotton, corn and legumes constitute the major crops of the rotation, especially in the southern portion of the Cotton Belt. Special rotations are also being adopted in the wind erosion areas of U.S.A. and Canada, a grass crop sometimes being introduced at suitable intervals in order to improve the resistance of the soils to wind action.

Contour cultivation and planting and strip-cropping are rapidly developing as characteristics of conservation agronomy in all parts of the world. The old system of ploughing, planting and cultivating crops in straight rows regardless of the slope of the land is being replaced by strict adherence to the contour lines marked out accurately on the slope by an engineer. Thus

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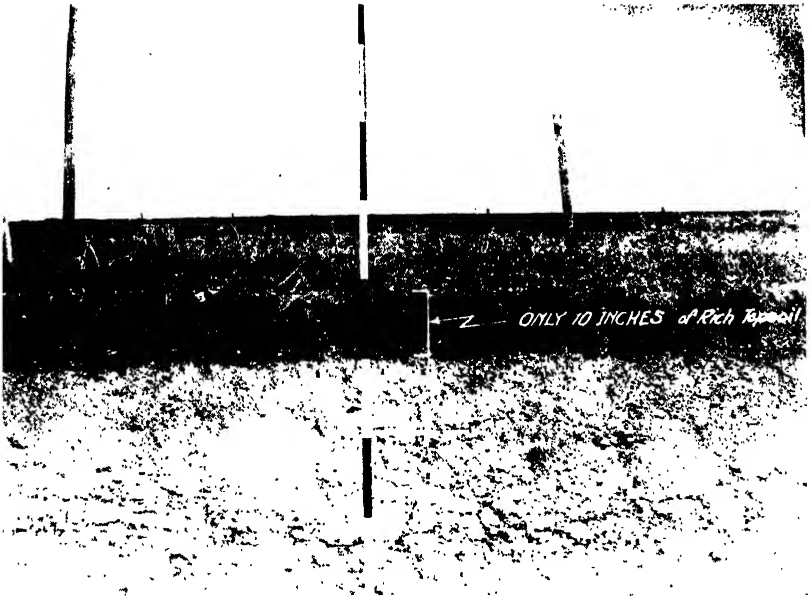
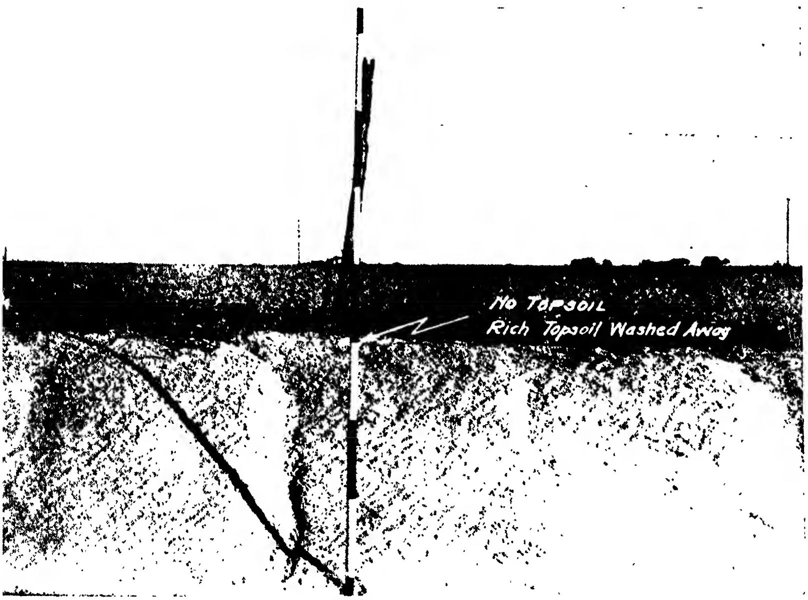
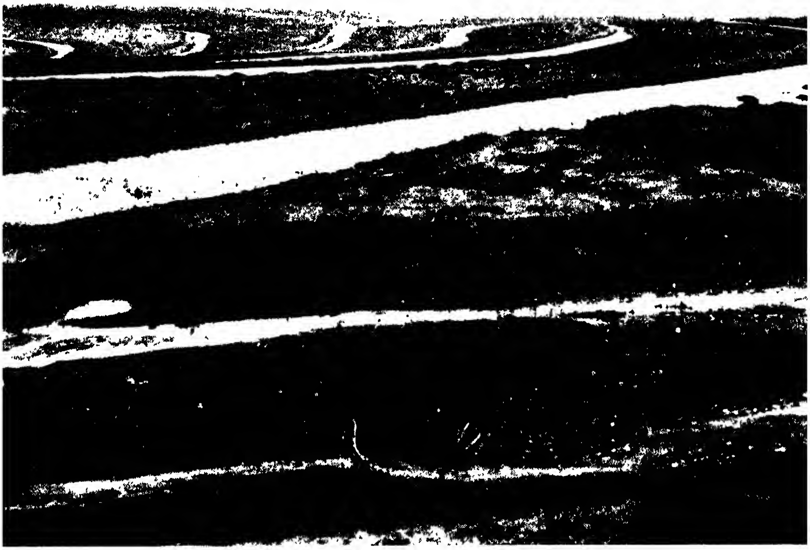
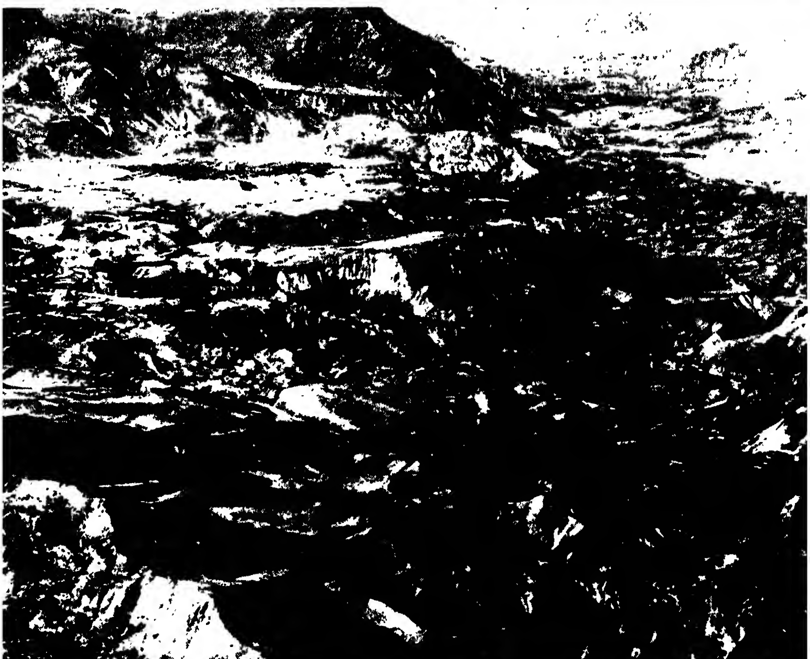
22. Two stages in the erosion of the soil type illustrated in Fig. 21 *b*. Note the poor structure of the half-eroded compared with that of the uneroded soil (21 *b*), and the increasing poverty of the vegetation, as erosion progresses. In the lower picture, the entire topsoil has been washed away.


ONLY 10 INCHES of Rich Topsoil


No Topsoil
Rich Topsoil Washed Away





an opportunity is no longer afforded to the excess water to flow rapidly down the plough furrows, or between the rows of the standing crop, taking with it valuable topsoil and forming rills and incipient gullies. It is found that contour cultivation actually facilitates farm operations, particularly if transverse fences and other obstructions are removed.

It is a natural step from cultivation on the contour to rotation on the contour, i.e. strip-cropping. This method can be adopted alone when hillsides are not so steep as to require the construction of terraces; it relies for its effect upon the utilization of the land for that type of vegetation to which it is best adapted from the point of view of soil and water conservation. It has been used to protect large fields with long slopes which have been ploughed and cultivated as a unit, leaving the entire area exposed to erosion. The greatest loss occurs when the ground is bare of vegetation. Harmless run-off from the tops of the slopes has the opportunity to accumulate momentum, volume and soil load until it becomes destructive as it approaches the foot of the slope. A strip-cropping system on the contour breaks up the length of these slopes and provides partial protection for the area at all times of the year.

Three chief types of strip-cropping are used in the United States.

Contour strip-cropping is the production of farm crops in long strips of variable widths on which dense erosion-control crops alternate with clean-cultivated or erosion-permitting crops, placed across the line of slope approximately on the contour (Fig. 25). It may be impossible to have parallel strips with all the rows of a given strip exactly on the level or true contour because of variations in the slope of the land; it is, however, sometimes permissible to deviate to some extent in order to have cultivated rows of uniform length and to avoid point rows.

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23 *a*. Broad-base terraces on 4 to 7 per cent slope. These terraces held over five inches of rain falling over a period of a week but only a small percentage of the land gained any benefit from it. Terraces did, however, prevent the enlarging of gullies which had started previous to the terracing. See page 110.
23 *b*. Bench terraces in the Colca Valley, Peru. See page 110.

Field strip-cropping is the production of regular farm crops in more or less uniform parallel strips laid out across the general slope but not on the true contour (Fig. 26). This modified form of contour strip-cropping is applicable to uniform, gradual slopes on soils resistant to erosion. It is a simple method which may frequently be used in connexion with grassed waterways, where the true contour cannot easily be followed.

Wind strip-cropping is the production of crops in long, relatively narrow, straight, parallel strips placed across the direction of the prevailing wind without regard to the contour of the land. This type is effective in preventing wind erosion but may be of little value in conserving water, unless combined with other special measures (see Chapter XIII and Fig. 39 *b*).

In the cultivation of land under the strip-cropping system, the plough furrows and later the harrow grooves, carried round a slope approximately on the level, tend to obstruct the free flow of water down a slope. The rows of cultivated crops and the furrows made by the cultivator serve as checks during the growing season; the lower border of the strip becomes slightly ridged to serve as a final obstruction to the flow of water to the next strip below.

In the United States, strip-cropping, combined with contour cultivation and terracing where necessary, has been proved to be very economical and effective, and the most practical method of controlling erosion and conserving soil and water on cultivated land. Its increasing adoption throughout the country is doing much to counteract the effects of the original rectangular lay-out of lands, a system which tried 'to fit square farming to a round country'. The past and present pride of the ploughman and farmer in their straight rows in rectangular fields, based upon tradition and teaching, will have to be gradually changed in those countries affected by the erosion problem, and first place given to the man who can follow a contour line with absolute accuracy.

In addition to its influence in checking the movement of rain-water, strip-cropping also filters out the soil being carried off and increases the absorption of rain-water by the soil. The innumerable obstructions offered in the alternate strips slow down the rapid flow of water, permitting it to soak into the soil,

and, by spreading the water, prevent it from concentrating in low areas and gullies. The filter action of the control strip is very important.

Another advantage of strip-cropping is that it necessarily encourages rotation farming, so essential in any system of conservation agriculture. The type of rotation used depends upon the locality and upon the facts already stated in this chapter regarding the relative merits of different crops in preventing erosion. The adoption of strip-cropping will necessarily tend towards an increase of mixed farming; its introduction will be most difficult in areas where only a limited number of crops is now produced, e.g. in the single-crop sections of the United States. An ideal rotation would permit the cultivated crops to follow the sod or hay crops and the small grains (cereals) to follow the cultivated crops.

Soil fertility and organic content under humid conditions are materially increased by ploughing under a good sod or legume before planting the land to a cultivated crop. Lucerne, sweet clover, red, alsike and crimson clover, vetches and peas may all be used successfully in the contour strip-crop rotation; legumes such as soy-beans and cowpeas, however, should not be classed in the erosion-resistant list. Although excellent as green manure, the mellowing and loosening effect they have on the soil renders them almost useless as erosion-preventing crops. In less humid conditions where the above legumes cannot be grown successfully, crops such as Sudan grass, the stooling varieties of grain sorghums, millet and winter cereals can be substituted. Practically all the winter grain crops (rye, oats, wheat, barley) and mixtures of rye and vetches or Italian ryegrass and crimson clover prevent erosion as soon as they establish a ground cover and can be used effectively on the control strips. Spring-sown cereals are less suitable, as large areas or double strips are left unprotected at one time.

The crop sequence within and between the strips is an important consideration in this type of cultivation. Cultivated crop strips must not be adjacent, nor should any adjacent strips have the same planting or harvesting dates. If possible, a cultivated row-crop strip should be bounded above and below by a hay strip, but as a hay surplus would thus be produced, a cereal strip is frequently introduced in place of one of these hay strips.

Where fields are broken by critical slopes of 15 to 20 per cent or more, strip-cropping, even in combination with other conservation measures such as terracing, has to be replaced by special types of perennial vegetation. These should be perennial forage crops rather than trees, to provide protection throughout the year at points in the field where erosion is most critical; they may be used as hay meadows when the forage crop becomes established. As it is impossible effectively to control erosion on these slopes with row-crop farming, this permanent vegetative cover is essential in erosion areas if the control measures in the remainder of the field are not to be rendered useless.

Where contour farming and strip-cropping have failed to give the necessary degree of conservation of soil and water, a system of terracing may have to be employed to deal with the excessive amounts of water falling on and flowing down a particular field. The common types of modern terraces are merely earth ridges or embankments constructed across the slope of a field, behind which is a broad ditch designed to collect the water from the slopes above, to hold this water until some has soaked into the ground and to conduct the excess away slowly and carefully without damaging the land below.

The modern broad-base ridge terrace does not completely stop the movement of the soil, as there is considerable movement downhill between terraces. By reducing the speed of the run-off water, however, the terrace channels cause the water to deposit at least part of its load of soil particles; although the movement may not be stopped entirely, most of the soil remains in the field.

Terracing alone does not protect a field against erosion, but if employed as part of a complete scheme of soil conservation with contour cultivation, strip-cropping, rotations, etc., it makes soil building possible at a rate which approaches the rate of soil loss. It is possible to crop the terrace channels, which are maintained by regular ploughing. Terraces do not hinder the usual farm practices and actually facilitate the arrangement of fields for strip-cropping and contour cultivation.

The first terrace is placed near the crest of the slope to be treated to prevent the initiation of erosion, and the remainder suitably spaced on the hillside below to serve the same purpose. Some terraces are level longitudinally, but the general practice

is to allow a gentle and possibly a variable gradient to ensure that the excessive rainfalls shall flow slowly to a suitable outlet at the end of the terrace, and not over the crest of the terrace to the land below. The separate terraces are spaced as wide apart as possible, bearing in mind the erosion-resisting capacities of the soil and slope. Wide spacing requires larger capacity in the terrace channel, while good cultural practices will reduce to a minimum the amount of run-off from the catchment area under an excessive rainfall.

There are several different types of broad-base terrace, of which the best-known are the Mangum terrace, named after its originator, P. H. Mangum of North Carolina, and the more recent Nichols improved terrace, developed by M. L. Nichols, regional engineer of the U.S. Soil Conservation Service, and now being widely used in the United States (Figs. 25 *b* and 27). The latter type of terrace is a shallow waterway which is built entirely from the upper side, i.e. the soil is moved only downhill; the terrace has a shallow broad channel cut down into the soil or into the subsoil below the natural level of the field. No effort is made to maintain a distinct terrace ridge, as this is blended into the slope after the field is worked. The Nichols terrace cannot be used successfully on slopes greater than 12 to 15 per cent in the south-eastern United States, while on certain soils it is effective only on less than 12 per cent slopes. In deciding whether a slope is too steep to be terraced, it is necessary to consider the cropping system, the soil type, the skill of construction and the care in maintenance.

Dr. Quincy C. Ayres, in his book *Soil Erosion and its Control*, gives a comprehensive description of terrace design and location, construction methods, machinery, costs and maintenance, but concludes that 'nothing is more vital to the success of a system of terraces than good dependable outlets, and strangely enough, nothing seems to have been more neglected. . . . The selection, preparation and maintenance of outlets in erosion-proof conditions are indeed problems of prime importance; and no part of the terracing program is more subject to local variation.' The stream of water flowing along the base of the terrace is a potential eroding factor when it reaches the end of its controlled movement in the terrace and great care must be taken to ensure

that it is properly disposed of without causing damage to adjacent, possibly neighbours', land. This may be done by conducting it into an adjacent area of woodland or partially grazed pasture, or into specially constructed outlets depending upon vegetative (grass and clover mixtures) or mechanical means for their control of erosion. Particular care must be taken properly to adjust the velocity of the flow of water.

This represents a rough outline of the general technique which has to be considered in framing a system of conservation agriculture for the principal cultivated crops in the United States. Provided that they are grown on the more gentle slopes, and that the steeper slopes are safely conserved by permanent vegetation such as woodland and pasture, it is probable that soil loss and water run-off will be reduced to a minimum by the adoption of the special methods of agronomic conservation. In the great majority of cases the simpler methods of contour cultivation, crop rotation and strip cropping will give the necessary protection; where these fail, terracing will have to be added to the programme. The simpler methods can be adopted by all farmers irrespective of their economic position; terracing requires special equipment which is not available to all, except on a co-operative basis.

It is probable that similar techniques with local variations will gradually come to be adopted in the other countries affected by erosion. For example, the more advanced farmers in South Africa are using contour cultivation, strip-cropping and terraces. The problem of improving the organic matter content of the soil and the general soil fertility is also receiving attention. Further north, in East and West Africa, cultivation technique is less advanced, the authorities being more concerned with the introduction of mixed and settled farming in place of the shifting cultivation which has had such a disastrous effect on the soil fertility. In Kenya, a certain amount of construction of stone terraces has been done by the natives, in order to protect the small plots of cultivated sloping land. The use of broad-base terraces is also recommended, but the cost of construction makes them uneconomic for any but European-owned land.

The foregoing paragraphs have described the changes in technique which are taking place in the cultivation of the more

common arable crops, e.g. cereals, maize, sorghums and rotated crops. Similar developments are also occurring in the cultivation of specialized crops, e.g. plantation crops, orchards and vegetables.

The type of cultivation which is being used for certain plantation crops, such as rubber and tea, has already been mentioned in the preceding chapter. The rubber estates in Malaya are tending to adopt the 'forestry' system of cultivation for rubber, the aim of which is to establish and maintain a cover of desirable types of indigenous plants, the less desirable growths being gradually eliminated. Desirable types include erect shade-tolerant species with large succulent leaves and deep rooting habit, while the undesirable are varieties with leaves and stems which are resistant to decomposition. The usual method of control is to slash the plants when they reach a height of about five feet and to remove those which have become too weedy by cutting the stems just below ground level. Although this system would appear to be successful in Malaya, doubts have been expressed regarding its application in Ceylon. The Rubber Research Scheme (Ceylon) is therefore recommending that local estates should endeavour to establish leguminous ground covers, in the meantime retaining naturally occurring plants of a desirable type, including rubber seedlings up to a height of 6–8 feet.

The only steps which can be taken in Ceylon with regard to earthworks in mature rubber plantations are the improvement of existing drainage systems with a view to retaining a maximum proportion of the rainfall on the land and ensuring that the surplus water flows away with a minimum erosive action. In modern practice side drains are cut on the contour and consist of a series of silt pits connected by shallow channels and overflowing into the leader drains. In preventing soil erosion in new clearings or replanted areas, the construction of earthworks precedes the establishment of a ground cover. When it has been decided whether it is desirable to prevent run-off of rain-water from the land, a decision which depends upon the rainfall, the construction of the two usual forms of earthworks for retaining the rainfall, namely, contour platforms and contour trenches, can be carried out. When it is desired to retain only a propor-

tion of the rainfall, planting can be done on the contour with level silt pitted drains.

The great care which is given to the terracing and preparation of the land prior to planting coffee in Java is shown by Figs. 28 *a* and *b*. The planting requirements for the following year are prepared in good time. The land is cleaned and dug and, without exception, some suitable method is used to prevent soil erosion, the method varying according to circumstances. The cost of preparing the land from clearing to planting is stated to be about 67s. per acre (with cheap labour); the figures for land which does not require such expensive terracing are very much lower. When once established, the cost of upkeep is negligible. There is still some doubt regarding the use of cover crops. Selective weeding is practised on a fairly large scale, indigenous weeds being preferred to introduced leguminous crops.

Erosion has caused serious damage in Arabica coffee plantations in Tanganyika. In some cases it has become necessary to replant if any financial return is to be obtained. It is recommended that contour lines (trenches, hedges, weeds, etc.) should be arranged at frequent intervals rather than imposing works at wide distances apart down the slopes. It is advised that six-yard horizontal intervals be allowed between the trenches on a gentle slope and a vertical distance of four feet between the trenches on a steep slope. The conclusion drawn at the Coffee Research Station, Lyamungo, Moshi, is that contour ridging is the cheapest effective method in coffee plantations; terracing appears to be unnecessary on a 1 in 6 slope and box ridging has no particular advantages. Banana mulching is as effective as any measure and also conserves moisture; further experiments are in progress with this method, which is a simple native practice.

These examples will serve to show the types of measures which are being adopted under the conditions of plantation agriculture. Other crops which are receiving similar attention include cotton, cocoa, tobacco, bananas, tung oil and all the miscellaneous crops of tropical countries. The problem of the conservative cultivation of one or other of these crops arises in all parts of Africa, the East and West Indies, India, Ceylon and the Far East, and North and South America. Each country will

tend to develop a type of agronomy suited to local conditions of soil, climate and the economic position of the agriculturists.

For vegetable cultivation, strip-cropping with or without terracing is a practical method of control, but various adaptations are necessary to conform with the conditions imposed by an intensive cropping plan. The most common method involves the laying of contour lines with parallel cultivated strips 50 to 100 feet wide, depending on the slope. Contour lines are laid out with a maximum deviation of one-half of one per cent. Below this cultivated strip another contour line is run, but allowance is made for at least a 24 foot width at the narrowest point between the lower contour line and the last row of cultivated strip above. This leaves an irregular or compensating area between each cultivated strip and the next contour. Generally this area is sown to cereal or permanent hay. By reversing the area in cultivation and laying out the rows parallel to the lower contour, advantage is taken of the organic matter developed through the grass residues. The use of broad-base terraces has proved to be a practical and effective method of erosion control on vegetable farms on the Atlantic seaboard of the United States. Successful results have also been obtained in the introduction of terrace-garden cultivation among native tribes in Africa; for example in Basutoland, where some hundreds of native gardens have been laid out on the terrace principle as the result of advice from the local authorities.

Years ago the absence of an under-storey of vegetation in orchards of apples or peaches was regarded as indicating superior farming. This clean cultivation and the depletion of organic matter in the soil, together with the fact that orchards are frequently on sloping land, account for much of the erosion which has occurred. In more recent years the clean cultivation of apples has been discouraged in the United States. Although it is now usual to cultivate peaches in both directions during the growing season, cover crops remain on the land for the remainder of the year. The Soil Conservation Service recommends that, if cultivation in both directions is necessary, the first is done up and down the slope and the second and last across the slope. Temporary cover crops, such as wheat, rye and a mixture of vetch and crimson clover, are generally used in peach orchards,

but there has been a distinct trend towards the use of a permanent cover crop such as alfalfa or sweet clover with grasses in the apple orchards. These crops are cut when it appears that they are beginning to deprive the trees of moisture. A method which may be considered as a compromise between clean cultivation and a permanent cover is that in which the alternate middles are placed under a legume-grass cover.

When it is impossible to secure an adequate growth of a cover crop or to use contour methods for erosion control, mulching offers the best substitute. Mulching of even half the area has been found to be sufficient for erosion control. The cost of mulching material and the risk of fire during dry weather have prevented its wider use; the fire hazard is, however, negligible after the mulch has been packed by orchard traffic and made moist by rains, while the salt hay deposited on certain parts of the Atlantic coast highways is used as a cheap form of mulch.

Terraces may also be used for orchard planting, especially when new areas are being laid down. Terraces have a beneficial effect on the conservation and uniform distribution of moisture to the trees, particularly where it is possible to plan a terrace for each row of trees.

CHAPTER X

Reclamation of Gullies

Gullies as septic foci. Origin. Prevention. Mechanical control or revegetation. Suitable plants. The black locust. Vines and spreading legumes. Stoloniferous grasses. Check dams.

The reclamation and control of the great and little scars, produced on the earth's surface as evidence of the misuse of land, and variously known as gullies, arroyos, barrancas, dongas, wadis and so forth, are an essential part of any conservation programme, as they are equivalent to septic foci from which the wasting disease may spread to adjacent unharmed and non-eroding land. The deeper a gully grows, the more water does it collect in its stream bed and the more powerful does it become as an eroding factor.

The greatest damage caused by gully erosion is in the removal of fertile soil. In addition, gullies prevent cultivation, as they cannot be crossed by cultivating machinery; they grow rapidly, undermining farmhouse or farm buildings, public highways or farm roads; the material they carry causes the silting of reservoirs or irrigation channels or is deposited on rich bottom land, reducing its productivity.

Gullies are caused by erosion due to water collecting and flowing at a velocity sufficient to move and carry away soil particles, and may arise in various ways. Surplus water flowing down rolling or hilly land collects in depressions on the surface, forming rills or streams with power to wash away the soil. This power to erode increases as the flow increases in size and velocity, and a gully will be formed and enlarged with each succeeding rain, unless the draw is protected by grass or other vegetation. Waggon tracks, cattle paths or plough furrows running

up and down the slope can all lead to dangerous accumulations of water.

When the excess water collected by this head-erosion flows rapidly from the field slopes to the natural drainage channels below, the capacity of these is greatly taxed by the rapid delivery of water from all parts of their watersheds, and they become greatly enlarged and deepened by the erosive action of the excess water. As the stream bed in them falls lower and lower, the smaller gullies and rills from the field slopes become steeper and more dangerous as erosion centres. At first the tributary gullies empty their streams into the main channel over the edge of a bank, thus producing waterfall erosion, the type responsible for the deepest gullies and chasms. The falling water undermines the edge of the bank, which gives way, and the waterfall moves upstream rapidly, especially in erodible soil. As the gullies extend backwards, they cross tributary watercourses or natural depressions, which then also form waterfalls and develop branch gullies. Gullies of this type may be formed in almost level country, their growth depending upon the size of the drainage area rather than upon the slope of the land.

Gullies can be prevented from developing by the adoption of the methods of agricultural conservation described elsewhere, i.e. those methods which will cause the soil to absorb as much of the water as possible and provide natural outlets for the slow disposal of any inevitable excess.

Some gullies may be controlled by appropriate ploughing, cultivation and terracing of a field, with the use of special equipment such as the 'bull-dozer' for particular cases, or by the method evolved by Mr. Howard Hobson in the Orange Free State and described on page 66. If, after ploughing in, the depressions still tend to produce gullies, they can be seeded with a good pasture mixture; trees may also be planted to hold the soil in place and temporary dams constructed to hold any loose soil which might be washed away while the vegetative controls are becoming established (Figs. 30 *a* and *b* and 31 *a* and *b*). These grassed waterways may then be incorporated into the terracing system of a field, acting as natural outlets for the slow removal of water delivered by the terrace outlets. Natural revegetation of gullied land is usually possible, but the process can be a slow one

and generally cannot keep pace with the rate of growth of a gully. In addition, volunteer plants cannot become established on the unproductive subsoil surface of the larger gullies.

When it is impossible to fill a gully and restore it to crop use, or partially to fill it and use it as a drainage channel, other steps must be taken to protect it and the adjacent land against its further enlargement. This may be done by the use of particular types of vegetation or by the construction of dams at appropriate intervals in the gullies to arrest the flow of water.

The vegetation of value in reclaiming gullies and chasms should be characterized by rapid growth and good soil-binding qualities. The types of plants which may be used include some trees, a number of vines and creeping plants, and stoloniferous grasses.

A tree which is widely recommended on account of its spreading and interlacing root system is the black locust, *Robinia pseudoacacia*. This leguminous tree makes rapid growth on good soils, grows even on poor and dry soils, is easily propagated, enriches the soil with nitrogen, and produces very durable wood of value for fence posts, stakes and poles; its value for gully control is shown in Figs. 30 *a* and *b*. It is widely planted in the United States in areas which are neither too hot nor too cold, and where it is free from attack by the locust borer. In any situation within its range of cultivation the black locust reaches commercial maturity comparatively early, and should be cut before it is twenty to twenty-five years old. Under unfavourable conditions it is frequently seriously damaged by insect and fungus diseases after fifteen to twenty years, while in favourable regions it lives for fifty or more years before showing signs of old age.

It is possible that this valuable species, or the related and superior shipmast locust, may be of service to conservationists in many eroding parts of the world. Possibly other leguminous trees with similar qualities may be found in local floras elsewhere for the reclamation of deep gullies, in combination with other plants. The soil-enriching qualities of a leguminous tree lead to the improvement of the poor eroded soil upon which they are grown, and to the subsequent formation of a legume-grass association of considerable value as an erosion-control factor.

Heavy sods of bluegrass and other palatable species are frequently developed on locust plantations on gullied land formerly too impoverished to support any vegetation.

Other trees of value in gully control include species of *Pinus*, poplars and willows. Of the various vines and creeping plants useful in revegetating gullies, perhaps the most promising is the kudzu vine (*Pueraria thunbergiana*), a native of China but now widely grown in parts of the United States, Southern Rhodesia and elsewhere, either as an ornamental plant or a forage crop This vine usually makes phenomenal growth; it has a tendency to clamber over trees, tall grass and other vegetation, but if established on barren, eroded soils the vines cling closely to the ground. This legume both enriches the soil and provides large quantities of palatable forage. It is propagated from 'roots' or 'crowns'.

Other vines in the United States with a habit of growth which suggests their value for gully plantings include the common ornamental wistaria, the trumpet creeper (*Bignonia radicans*), and the trailing wild bean of northern Mississippi (*Strophostules helvola*). Elsewhere, legumes of local floras may be found to have similar qualities. Another species effective in controlling soil wash due to the mat of protective foliage which clings closely to the soil is the common lespedeza (*Lespedeza striata*), a plant which appears to be able to grow on a great variety of soils, including heavy clays and other soils in poor physical condition.

Any grass species with a stoloniferous habit, a rapid rate of spread, and a good soil-binding root system will be found to be suitable for gully control. The actual species selected will vary with the locality but typical examples of widespread species include Bermuda grass (*Cynodon dactylon*), centipede grass (*Eremochloa ophiuroides*), bents and red-tops (*Agrostis* species), *Paspalum* species, kikuyu grass (*Pennisetum clandestinum*), Johnson grass (*Andropogon halepense*) and others. Where stock are not likely to damage the vegetative cover of a gully while grazing, palatable grasses can be used, but in other cases it may be advantageous to utilize some of the species generally recognized as undesirable and unpalatable for gully reclamation and erosion-control work in general. Where rapid establishment is

desirable, planting of turves, sods or root cuttings should be used in place of seeding.

Check dams can be used alone or in combination with vegetative control methods, the object being to reduce the erosive velocities of the water by a series of checks which gradually transform the gully gradient from a uniform steep slope to a series of steps (Fig. 31 *b*). These dams may be of a temporary nature, to be used in combination with vegetation, or of the more expensive semi-permanent type which do not require supplementary vegetation for ultimate control to the same extent. Temporary dams are built of stakes, brush, straw, logs, loose rock or woven wire; the more permanent dams are constructed of earth, masonry or concrete. Most temporary dams are porous, the spaces in them being gradually filled up with the material brought down by the water, but the structure is never subjected to pressure from the water coming from above. Most permanent dams are watertight, the water having to flow over them, be directed around or carried through them in a conduit. As the successive steps are filled up by silt, a further series of dams can be constructed in the intervals between the original series and the process of filling up and dam construction repeated until the gully is completely filled.

Where gullies are formed in livestock areas and a supply of water for the stock is required, the dam to be constructed may be of a type which will provide considerable storage facilities for emergency purposes. Reclaimed gullies also have an important role as wild-life refuges.

CHAPTER XI

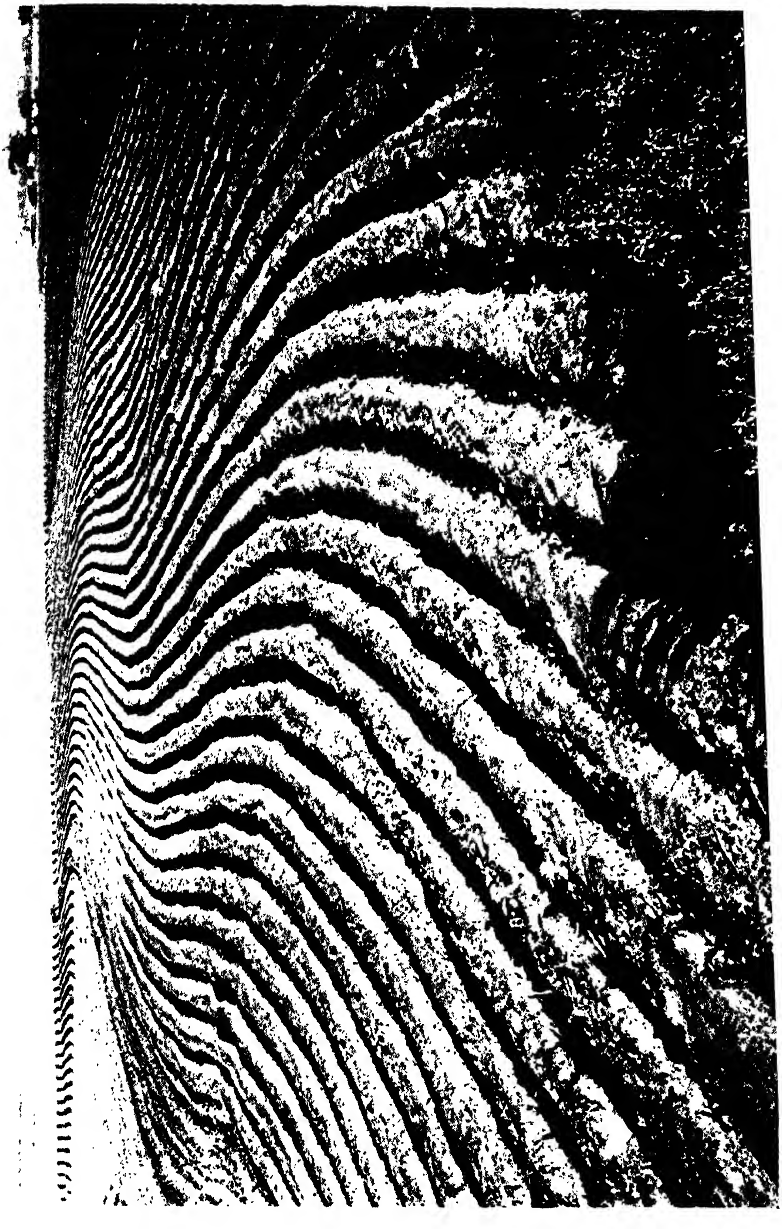
Pastures, Range and Veld

Conservation value of a grass sward. Grazing value and conservation value. Development of erosion on humid grasslands. Ideal sward. Wild white clover. Overgrazing on semi-arid grasslands. The goat. Burning. The desert fringe. Ploughing of semi-arid grasslands. Readjustment of stocking capacity. Enclosure. Improving the water relations. Contour furrow. Water spreading. Reseeding. Transplanting. Pasture research in Africa, India, North America and Australasia. Exploration.

A grass sward well managed is an efficient cover for preventing erosion and reducing run-off; a grass sward badly managed is a dangerous thing, with the poor vegetation incapable of guiding the rainfall into the soil and the bare ground favouring soil packing and the beginnings of rill and later gully erosion by water, or the wholesale removal of soil by wind.

A good sward has numerous merits from a conservation point of view. It covers the surface of the ground, protecting it from the direct impact of the falling raindrops and thus keeping the pores of the soil open and capable of receiving excessive amounts of water. The leaves of the herbage assist in guiding the falling raindrops to the soil. The humus layer below the herbage is capable of storing many times its volume of water. In this way, a good grass sward favours a high degree of infiltration and ensures that any water which does flow away as run-off is clear and has little eroding power. The root system of the grass is of value in protecting the soil against erosion, particularly the action of wind. Where the sward contains a legume, the soil fertility is

24. Oklahoma, U.S.A. Contour ploughed field which has had one levelling of harrow in preparation for planting cotton. See page 128.



considerably increased by the nitrogen fixed by the legume, thus promoting the development of a superior botanical composition of great conservation value.

Pastures and range lands in different parts of the world naturally vary widely in these respects, but in general it can be said that the plants which are of greatest value for grazing purposes in any particular area are also those that are most conducive to water absorption and soil retention. There are great differences between species as regards degree of ground cover, stoloniferous or spreading habit, development of an extensive root system, and other characters of conservation value. For this reason it is impossible to generalize on the relative merits of different pasture swards, the experiences under one set of conditions being inapplicable under others. Each country must work out its figures for soil loss and water run-off for its own conditions and its own type of management, as is now being done in the eastern and western United States, at Pretoria in South Africa, Mpwapwa in Tanganyika Territory, and centres in India.

It is the semi-arid grassland areas which have suffered most from erosion, but extensive damage has also been caused to grass swards in the humid temperate parts of the world. In the latter case, it has been due either to overgrazing or undergrazing, or similar incorrect types of grassland management in climatic conditions characterized by sudden torrential rainfalls and possibly also by summer drought. Overgrazing leads to a deterioration in botanical composition and an increase in stemmy annual grasses and weeds, as well as to an increase in bare ground, all factors conducive to erosion. Undergrazing causes the tall stemmy types of herbage to become dominant; the soil-protecting bottom grasses and clovers are choked out, with the result that again there is an increase of bare ground. In both cases the raindrops fall directly on to the soil, puddling the surface and clogging up the pores with silt; infiltration into the soil is reduced, run-off of silt-laden water increases, and the cycle of erosion begins.

It is obvious that erosion control and soil conservation on grasslands of all types are synonymous with good grassland

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25. South Carolina, U.S.A. Strip-cropping. See page 129.

management. In humid areas, a high-class erosion-resisting sward should be maintained. If the land is to be resown, care must be taken to plough at the correct time of the year, avoiding as far as possible the exposure of unprotected soil to water action during periods characterized by torrential rainfall. The seeds mixture should also contain some rapidly growing species, to give protection to the soil while the chief constituent species are becoming established. The chief species will naturally be selected on the basis of local requirements and conditions, and should include suitable 'bottom' species to form a close sward capable of protecting the soil from the direct impact of falling raindrops. Sward formation can be encouraged by various means, such as application of fertilizers, regulation of grazing to carrying capacity and seasonal growth, rotational grazing, and resting as far as possible during droughty summer periods, in order that the species may not be weakened by excessive grazing during that period, with a consequent reduction in conservation capacity. This may necessitate the cultivation on other parts of the farm of supplemental grazing crops and forage crops, to tide over the period of dormancy in the pastures proper.

The species composing an erosion-resisting sward under humid conditions vary to some extent, but in general a spreading or stoloniferous habit is of value in the grass species in the mixture, while the inclusion of a prostrate or creeping legume such as wild white clover, lespedeza or trefoil will assist in providing ground cover and in improving the fertility of the soil. Research at Cornell University has shown that wild white clover provides almost complete control of soil erosion and greatly reduces loss of water by run-off from the surface during heavy rains under the conditions of the north-eastern United States. This was found to be due to prevention of impact of raindrops on the soil, retardation of rate of flow of water over the surface, and increased porosity of the soil resulting from the accumulation of organic matter and the activities of earthworms. A pasture plot treated with superphosphate and lime was found to contain almost four times as many earthworms per acre as the untreated plot; the effect of the treatment was the development of a dense sward of wild white clover. Where fertility conditions are not sufficient to support a sward of this

clover in combination with a high-grade grass species, some other legume such as lespedeza may be introduced to provide a ground cover highly resistant to erosion.

A sward of the above type is of value for permanent erosion control on slopes which are to be 'retired to pasture' and left unploughed in the future. In addition, however, special attention should be given to the conservation values of the species used in the temporary ley, in relation to the crop rotation scheme for the farm as a whole. This temporary grass-legume sward will probably be incorporated in a strip-cropping scheme and generally contains species of a hay type, such as the grasses cocksfoot, timothy, brome grass and Kentucky bluegrass, and the legumes alfalfa, red clover, alsike clover and related species. Alfalfa-grass mixtures sown for soil conservation have many advantages over the seeding of grass or alfalfa alone; the practice is spreading rapidly in the northern States of U.S.A. and is being recommended by the Soil Conservation Service.

Where erosion on humid grassland has been severe, more drastic measures of gully control may have to be adopted, for which purpose other ground covers with a more rampant habit of growth, such as kudzu vine, kikuyu grass, etc., can be employed to provide complete protection (see Chapter X).

The carrying capacity of semi-arid grassland such as steppe, range, savanna or veld is low compared with pastures under more humid conditions, and in addition the principles of grazing management differ. Great areas of range and veld have been ruined by overgrazing, due either to overstocking of the entire area or to badly distributed stocking consequent upon inadequate watering facilities for animals. The results are again a deterioration of the original vegetation under the constant grazing and treading of stock, through the ecological stages of retrogression characterized by the development of poorer types of perennial grasses, annual grasses, weeds and in some cases useless bushes and scrub. In bringing about this retrogression, such factors as the relative palatability of species and the grazing habits of the different animals are of importance; the goat in particular has been blamed for much of the denudation which has occurred, for example, in the Mediterranean area and around the Sahara, although it is not so much its grazing habits

as its ability to graze on steep banks and to destroy woody vegetation which has produced the serious results noted.

Annual burning of semi-arid grasslands has been a major factor in the exposure of large areas to erosion and desiccation. Grasslands throughout most of Africa are burnt annually for various reasons—to remove mature and unpalatable excess and to encourage young growth, to control bush or tall grass growth, or to reduce the danger of fire to adjacent forest areas and to clear dense grass for hunting purposes. Reliable data on the effect of burning are meagre and conflicting, although a considerable amount of attention has been given to the problem at Cedara and elsewhere in South Africa. R. Lindsay Robb concludes that 'the indiscriminate use of fire is to be condemned; nevertheless it may have a place—particularly in certain districts and on certain swards—as part of a controlled system of veld management, an operation to be performed only under certain clearly defined conditions. In our present stage of unenlightenment on the subject generalizations on burning are liable to be highly misleading since so much depends on such variable factors as the type of grassland, the successional stage within the type, the rainfall, time of burning, intensity of firing, and so forth.'

The most dangerous type of overgrazing is that which causes deterioration in the already sparse vegetation in arid and semi-desert areas, such as occur on the fringe of the Sahara, in South Africa, Australia and many other parts of the world where the ecological climax is in a delicate state of equilibrium easily upset by uncontrolled grazing, burning or other types of mismanagement. If properly used such areas have a definite though low carrying capacity, but their misuse is disastrous in its effect of extending the desert and increasing desiccation over a large area of adjacent country. This aspect of the grazing problem is discussed in Chapter XIII.

In many semi-arid parts of the world erosion on grasslands has been caused not by overgrazing, but by excessive ploughing of land for cropping. Once the grass root systems and the accumulated organic matter have disappeared under a non-rotational type of cultivation, the soil lies exposed during periods of cultivation and fallow to the eroding power of wind and water.

The chief cause of deterioration of semi-arid grassland areas is the absence of any regulation of grazing, or the failure to appreciate that the carrying capacity of such grassland is very low compared with that of more humid conditions. Before attempting control measures it is necessary to obtain some idea of the carrying capacity of the original undamaged vegetation at its highest standard of development. The seeding behaviour and regenerative powers of the grass species (few legumes succeed under these conditions) must be studied. Data should be obtained from ecological observations on the characteristic plant succession, with a view to discovering the stages of degeneration and regeneration of the gramineous and other constituents of the flora. The root systems of the different grass species should be compared in order to ascertain which should be encouraged from a soil-binding point of view.

With this knowledge it will then be possible to decide whether a reduction in stock numbers will be sufficient to favour the revival of the valuable species and also to what extent reseeding or planting of grass species is necessary and possible.

The degree of success to be obtained from enclosure depends upon the severity of the damage caused to the grassland, and in particular the duration of the overgrazing. Relicts of the original vegetation may persist for a considerable period under maltreatment and await only the rest provided by enclosure from stock to spread again vegetatively or by natural seeding. Special sowings of suitable species may be possible in some instances, but unfortunately many of the best species of semi-arid and arid grasslands are shy seeders and must be established by cuttings or similar vegetative means, processes which are laborious and expensive unless cheap native or other labour is available.

The regeneration of a degraded range may be accelerated by improving the water relations of the soil, particularly by ploughing contour furrows or similar devices to collect the run-off water and guide it into the soil instead of allowing it to flow down the slope. There is a great variation in types of contour furrows, but the general trend in North America is towards small furrows closely placed. In the Great Plains of the United States these permit 'better utilization of the moisture in the

production of vegetation, give greater capacity for the retention of moisture, and do not interfere with the mowing of weeds or the passage of machinery. There are innumerable examples which prove conclusively that subsoil moisture is being restored and pasture vegetation is increasing rapidly not only in quantity, but in per cent of coverage' (C. R. Enlow).

In discussing the future of South African pastures, T. D. Hall states that the farmers of that country 'have not realized what a revolution there has been in the knowledge and application of control methods by means of the contour furrow or ridge terrace, how much more efficient and cheaper it is than trying to dam dongas in the old way. The ridge terrace not only helps to restore and irrigate their veld, but it controls and slows down the flood waters, reduces silting to a minimum, prevents their dams from breaking and rejuvenates their springs. The use of the contour furrow is, in fact, the brightest spot on the dark horizon of reclamation. From what I have seen of actual examples of this method in restoring veld, increasing stock-carrying capacity, giving plenty of stored water and creating springs where none were before, I think the use of the contour furrow or ridge terrace will play a very great part in restoring South Africa's herbage and water supply.'

In constructing contour furrows, it is possible to arrange for them to be of a capacity sufficient to retain completely a rainfall of the maximum intensity per hour or per day characteristic of the surroundings. In order that the opened sward caused by the contour furrow may be healed as rapidly as possible, seeding with special pasture mixtures is a feasible practice, particularly in the more humid areas. In semi-arid regions where grass does not become established so readily, it is possible that a special type of machine can be used which places the furrow slice sod-side up beside the furrow, thus removing any necessity of re-seeding.

In connexion with schemes of water conservation on pasture and range land, it may be possible to utilize some of the conserved water for flood irrigation or for stock-watering purposes when stored in specially constructed dams. The provision of additional stock-watering facilities is an important problem in overgrazed parts of East Africa; for example, recommendations

have been made for the sinking of many additional water holes, in order to distribute the stocking in a more equitable manner. The effect of this practice on the underground water-table, and therefore indirectly upon the surrounding vegetation, is a point which deserves serious consideration. A system of water spreading may also be adopted whereby excess water is guided away from its usual course by damming or a similar method and spread over an extensive area of range land, provided this can be done without causing erosion on that land. The effect of flooding and silt deposition on the existing vegetation must be considered when adopting this practice; if the vegetation has not the capacity to grow rapidly through the silt, a bare surface is formed which hardens in the heat of the sun, thereby becoming much more dangerous as a run-off factor than the original, possibly overgrazed range.

Reseeding of depleted range and other types of semi-arid grasslands may be adopted, particularly where soil and moisture conditions are specially favourable. Where moisture is deficient, reseeding becomes more difficult and the species which can be utilized are few. Something can be done by appropriate timing of the sowing on the basis of the period of suitable rainfall but much research is still necessary, particularly on the development of revegetation methods sufficiently low in cost to be economically feasible on a large scale under dry conditions. When protection is an urgent matter, e.g. after a serious fire has denuded a critical watershed, emergency seeding of plants such as mustard may be made, possibly from aeroplanes, in order to provide very rapid re-establishment of vegetation before erosion and soil wash can set in.

Transplanting of grasses from which it is impossible to obtain sufficient seed is more uneconomic than reseeding, but nevertheless considerable success has been obtained from the practice; for example, in the reclamation work in Kenya, under the direction of the Reconditioning Officer of the Kamasia Reserve, where 20,000 acres have been reconditioned at a cost of about one shilling per acre, and in the western States of U.S.A.

As the research which is in progress in different parts of the world on the conservation of range, veld and other types of semi-arid grassland—the most important as far as we are con-

cerned—varies to some extent from country to country, a brief review may be appropriate at this point. In all cases it may be said that it is usual to make a survey of the area before formulating any scheme of reclamation and revegetation.

J. W. Rowland (Pretoria) states that the natural veld in South Africa will be the main source of food for livestock in the country for many years to come, artificial pastures being used mainly to supplement the natural vegetation at periods when it is either of little value or susceptible to damage by grazing. Veld research is being concentrated chiefly on the following aspects:

(1) Methods of management whereby the veld is stabilized at a useful level of productivity.

(2) The periods of value and the periods of shortage in veld production.

(3) Periods of critical growth when the vegetation may be said to be vulnerable or particularly susceptible to damage by grazing animals.

(4) The limits of botanical composition between which the veld can be changed by variations of grazing treatment.

'Correct management can undoubtedly increase the period of usefulness of the natural veld considerably. The problems vary widely in the different parts of the Union. In the sweeter, more arid regions, control must take the form of a limitation of stock numbers, and the provision of facilities for resting the veld during critical periods. The significance of different periods of rest is being investigated, together with tests of carrying capacity. On the sour velds, difficulties in achieving grazing control are ascribed mainly to the following factors:

(1) Wide variations in growth rate.

(2) The rapid decline in palatability and feeding value of the herbage as it approaches maturity.

'These two factors tend to intensify the evils of selective grazing. In order to eliminate this selective grazing, which can so easily cause steady deterioration, systems of subdivision into camps of different sizes have been devised; during periods of rapid growth, small camps are grazed rotationally, and during

periods of slow growth, large camps are used. The relative sizes of the camps must ultimately be determined by (1) variations in the growth rate during the summer; (2) the value of the herbage at the different seasons; (3) the length of the periods of rapid growth and of slow growth respectively.

'Simultaneously with this line of research on veld, artificial pastures are being investigated to find the seasonal grazing value of each type' (J. W. Rowland). Particular attention is being devoted in South Africa to woolly finger grass, of which several annual and perennial types occur in the Union.

Tanganyika and Kenya are also much concerned with grassland conservation. In the former territory research is carried on with regard to the relative values of local pasture and fodder plants and their behaviour under grazing in rotational grazing schemes, and run-off and erosion tests are made in semi-arid parts of the territory. The areas included in these last-mentioned tests include bare plots, non-cultivated, flat cultivated and ridge cultivated plots, a plot with the native grain crop (mtama . . *Andropogon sorghum* var. *vulgare*), a plot of African foxtail grass (perennial) and two deciduous thicket plots.

In Kenya the main line of development will probably be controlled grazing in the semi-arid drought-affected areas to prevent deterioration from localized overgrazing; stock farming in this type of country will remain on extensive lines. Attempts are to be made to conserve fodder as hay or silage. Suggestions have been made for a scheme of control for the drier areas occupied by native tribes, entailing the protection of areas in rotation, based on a knowledge of the periods required by the main herbage species to ripen seed. The mere closing of areas to grazing during one growing season has resulted in marked improvement; closing in rotation for a succession of growing seasons with grazing during the other part of the year would probably be adequate in many cases.

In discussing the grazing problem in the drier parts of India, R. Maclagan Gorrie states that constructive work can be done only on a self-help basis of free labour because the Government cannot afford to undertake it. The two main heads for the activities of each village or group of villages are (1) to develop fodder resources for local livestock, and (2) to improve the

standard of cultivation in any way which will tend to conserve soil and reduce run-off. The common lines of attack may be rotational closure of grazing land, partition of *shamilat* or common grazing ground, *panchayat* or village committee management, intensive improvement of natural grasslands including gully control and contour ridging on more gently sloping grasslands, development of tree fodder supply with controlled rotational lopping, development of green fodder crops and silage, determination of correct grazing incidence for local types of bush and grass, restriction of migrants and, above all, reduction of local herds with a campaign for fewer and better cattle.

The first reliable run-off figures for forest and grassland in India were quoted by Dr. Gorrie in an address to the Royal Society of Arts, London (May 1938). The results obtained during the first monsoon period were as follows:

TABLE II

	Grass 80 per cent cover	Grass and shrubs 90 per cent cover	Bare soil, grass clipped every 3 days
Percentage of rain which ran off:			
Out of total of 46 inches on 32 wet days during July-October 1937 - - - -	7	5	25
Out of total of 5¼ inches in 4 hours, the heaviest single storm - - - -	2·2	1·7	6
Weight of soil lost in lb. per acre:			
Carried away on 32 wet days -	3,500	3,900	18,500
Carried away by a single storm (5¼ inches) - -	260	307	3,511

The objects of research in the range country of U.S.A. and Canada are essentially similar. The practices of range management best adapted to the conservation of the land and consistent with maximum utilization, restoration and maintenance of the forage supply and the most effective production of livestock are

now widely applied; they have been enumerated by Dr. W. R. Chapline as follows:

(1) deferred and rotation grazing which permits full use of forage but delays grazing until after seed dissemination on a different portion of the range each year ;

(2) later opening dates for ranges, more in harmony with readiness of plants for grazing;

(3) a fairly good basis for determining the approximate grazing capacities of mountain range types;

(4) improved methods for grazing sheep and goats, such as open and quiet herding, and bedding them down in a new place every night, to avoid damaging the range through trampling and localized overgrazing;

(5) the obtaining of better distribution of cattle on the range through well-placed water places and better salting methods, thus bringing about more even and more effective use of the available range forage; and

(6) the eradication of tall larkspur.

The problem is serious in the arid pastoral areas of Australia, where any appreciable recovery appears to depend upon a readjustment of the stocking policy. The Ranson Mortlock Laboratory has been opened in Adelaide to devote special attention to erosion on Australian arid pastoral areas. An important aspect of its work will be a study of the relative merits of indigenous and introduced pasture plants. The outstanding species for low rainfall conditions in South Australia are subterranean clover and Wimmera ryegrass, but other species for more extreme conditions are required if the extension of the desert is to be prevented.

The search for suitable plant species to provide a cover on grassland, 'bush' and sandy areas under semi-arid conditions is one of the most important problems facing the conservation specialist. In most cases the indigenous species are found to be superior to the introduced, although frequently the former may be unsuitable owing to their inability to produce seed in sufficient quantities. Some countries are in a more favourable position than others. South Africa has a number of valuable grasses, and particular attention is now being devoted to the Digitarias,

mainly on account of their high carrying capacity, drought resistance and fairly high nutritive value, both during the growing season and in the dormant stage. The American range specialist has many valuable species in the grassland flora of the west. Even under more humid grassland conditions, specialists are recommending a return to the indigenous species as distinct from the introduced. The grasslands of New Zealand which were laid down in place of the former forests are largely composed of so-called 'English grasses', which have been established with great success. The native grasslands, however, have been exploited and deterioration has been general, especially in the great 'sheep-station' areas of montane and higher altitude tussock grassland. The seriousness of the situation has long been felt by the Department of Agriculture and an important preliminary survey was made by the late Dr. L. Cockayne which revealed the position as it existed from 1918 to 1922. 'Experimental plots were established, the lessons from which can now be read, and a further attack on the problems of increasing the carrying-capacity of the indigenous grasslands, of restoring the desert to fertility, and of soil conservation, is being made by the Fields Division of the Department of Agriculture and the Plant Research Bureau of the Department of Scientific and Industrial Research. In this work it has been decided not only to make more detailed surveys, but to establish experimental and nursery areas, so that the basis may be laid for a sound plan of procedure.

'As one of its aims the investigation will include the exploration of the possibilities of using to the best advantage the more valuable of the indigenous grasses, notably the different forms of blue-grass (*Agropyron scabrum*)' (Dr. H. H. Allan). Unfortunately for New Zealand the native species most needed have been so reduced in quantity that their seed has to be sought in odd sanctuaries such as cemeteries or gathered laboriously in the field by hand. It is considered that a sound preliminary step at this stage would be the establishment of a nursery for the assembly, cultivation and observation of promising species and strains of both native and introduced plants, for conditions under which the more restricted English grasses do not succeed.

Exploration in parts of the world with unsurveyed grassland

resources may provide valuable plant material. The Westover-Enlow expedition to Soviet Central Asia and Turkey brought back many valuable types for use in the revegetation programmes of the American Soil Conservation Service. In collecting grasses for erosion control, it is essential to cover as wide a range of species as possible, as the different types obtained are required for such varied purposes. Certainly any spreading or stoloniferous type is desirable even if rampant, while even unpalatable species may be of value in providing a permanent cover unaffected by animal grazing.

Mention has been made elsewhere of the many miscellaneous uses of grasses in a conservation agriculture, as, for example, in grassed waterways collecting water from terraces, grass plantings in gully control, grass covers on terraces, or on contour strips in orchards and plantations.

CHAPTER XII

Trees and Agricultural Conservation

World-wide destruction of forest cover. Little thought of results in terms of soil loss and run-off. Advantages of a forest cover. Siltation. Forests and climate. Reservation and utilization of standing forests. Sustained yield versus *boom and bust. Shifting cultivation. Tsetse fly. Reclamation by ecological methods or reforestation. Contour trenches. Teutonic and Mediterranean systems of reforestation. Shelter belts in Russia, U.S.A., Canada and Denmark. Miscellaneous uses of trees.*

The science and practice of forestry are related to the conservation of soil in numerous ways. The conservation of forests would, however, require a volume in itself, and the subject is growing rapidly as the fundamental knowledge, which is still scarce, becomes available from the varied ecological zones in which forests grow, both in temperate and tropical climes. We shall therefore confine ourselves in this chapter to a brief consideration of the extent of deforestation, the relation between forests, floods and climate, proper forest management, and methods of reforestation, devoting particular attention to the use of trees in the development of a conservation agriculture.

The spread of civilization across the world has led to the destruction of great areas of natural vegetation, and particularly of forest, woodland and scrub. Around the shores of the Mediterranean the original forest cover which came down to the water's edge was cleared to provide crop land, fuel, timber for building or ship construction, or was ruined by browsing stock, particularly the goat. In the more humid regions of Northern and Central Europe the clearance of the forest was followed by the development of an intensive type of agriculture. This, combined with the favourable type of climate, and particularly by a non-torrential type of rainfall, favoured the conservation of the soil's

fertility and therefore of the soil itself, save in the more mountainous regions of, for example, the French Alps and the Pyrenees. After the forests of the Apennines of Italy had been cut for ship and house building, attention was turned to the reserves in the Alps and Pyrenees and deforestation became excessive. Later, pressure of increasing population led to a disturbance of the balance between forest and alpine pastures, with subsequent erosion and flooding in the lower valleys. Now, however, the soil has become stabilized and erosion is slight, although floods are still frequent and may be inevitable.

Shifting cultivation and uncontrolled clearing and burning in India, clearing for rice lands in China, shifting cultivation and grass burning on the savannas, increasing desiccation and clearing for tsetse-fly control in different parts of Africa, clearing in the humid eastern United States for agricultural land and other purposes, lumbering in the north-western States and British Columbia, overcutting in forest regions of Australia, and wholesale clearing of the dense bush cover of New Zealand to provide grasslands, all are contributing factors to the enormous reduction of the world's forest acreage. This wanton destruction is all the more deplorable when the merits of a forest cover are considered in terms of soil loss and water run-off.

The precise value of forests in controlling floods is not yet fully understood, but it is certain that the major rivers which arise from the confluence of many tributary streams, the 'little waters' of the headwater supply areas, are much more regular in their behaviour if the upper reaches of the river basin are safely protected by a forest cover. The litter on the forest floor increases the absorptive powers of the soil, with the result that a high proportion of the rainfall is transferred to the ground-water table; the litter itself absorbs many times its volume of water. The peaks of run-off are thus reduced in height, with a corresponding reduction in number and height of floods. The water which passes to the ground-water table reappears gradually from springs and other sources, which thus have a more regular flow, a fact of great importance in reservoir and hydro-electric schemes. A change from a permanent to an intermittent stream flow is a characteristic of deforested watersheds. In addition, the water flowing from a well-protected watershed is

largely free from silt and does not cause siltation. The silt load of streams from deforested eroding watersheds is frequently very high (see Table 3).

The influence of forests on climate is a question which has received considerable attention, but the generalization frequently made that forests increase rainfall is not yet based on fact. A forest is the type of natural vegetation cover which develops under high rainfall conditions, and the existing rainfall is more effective and of greater value to agriculture and downstream industry if an upstream area is under a forest cover. This does not mean, however, that the planting of enormous blocks of forest indiscriminately will necessarily do anything in the way of transforming adverse climatic conditions. Under certain conditions and with certain types of rainfall, however, this may be so. There is still much to be discovered with regard to the relation between the plant cover, whether grassland or forest, and the hydrologic cycle. An interesting example may be quoted from the cultivation of cocoa in the Gold Coast; forest must be cleared for cocoa cultivation but the clearing reduces the humidity of the air which is so necessary for the growth of the cocoa tree. Thus a combination of forest strips or islands and cocoa plantations may have to be developed.

In many countries it will be necessary to place the forests which still exist in special reservations, or, if they are to be used, to ensure that they are cut on a sustained-yield basis. One of the cardinal maxims of forest management where tree cutting is necessary for the provision of timber is that of maintaining a sustained yield. The amount to be cut each year is adjusted to the annual growth increment of the stand. As compared with the present widespread 'boom and bust' method, the economic utilization of the forest resource is greatly prolonged. In addition to the prolongation of the period of commercial return, the indirect value of the maintenance of a forest cover upon the soil loss and water run-off cannot be over-

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26. Texas, U.S.A. Aerial photograph of approximately parallel strip-cropping. Long, gentle slopes broken with diversion ditches make strip-cropping a practical and economical method of erosion control. See page 130.

estimated. 'Sustained-yield' forestry often demands extraordinarily skilful management. The number of men capable of it may be the factor limiting its use.

The inhabitants of equatorial forest regions are slow to appreciate the indirect influence of forest growth in affording protection against adverse climatic conditions, but they would be more disposed to protect their forests if they were taught how to use them more fully. J. N. Oliphant considers that low-cost production of mill-sawn timber should be fostered and could be developed by indigenous agencies, as distinct from the selective exploitation by interests with capital from other countries. This indigenous development has been very successful in Malaya and utilizes large quantities of low-grade material which selective felling leaves untouched. The latter is a wasteful and impermanent practice, undesirable from the standpoint of the forest owner. Any type of forest utilization must, of course, be carried on with the correct silvicultural practices, directed towards the regeneration of the protective cover.

In certain regions forest destruction is due to fire. Measures which can be taken to prevent fires include the cutting of firebreaks, the planting of fire-resistant types of trees, and the organization of bush fire brigades with facilities for rapid reporting of forest fires and the means to control them as far as possible.

The creation of special forest reserves, supported by comprehensive forest laws, is of particular value in regions of shifting cultivation, or where there is a tendency for the clearing of forest for agricultural land to be carried to extremes. Under humid tropical conditions, where natural regeneration is rapid, the practice of shifting cultivation may be permitted, provided that the period under forest in the bush-fallow field-crop rotation is not reduced below the minimum which permits the increase in fertility in the fallow years to a level suitable for crop production. As practically always happens, however, this interval becomes too short, owing to increase in population or more settled conditions generally, and some readjustment is advisable. Forest reserves then become necessary, particularly in water-

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27. North Carolina, U.S.A. Cross section of a Nichols terrace. See page 133.

sheds and catchment areas; special types of mixed farming may be developed, the necessary organic-matter content of the soil being provided by animal manure or green-manure crops instead of by the bush fallow. The object is to change cultivation from a shifting to a permanent type adapted to the conservation requirements of the locality. The change is proceeding in Africa, the West and East Indies and other parts of the world, although not with sufficient speed to counteract the deterioration resulting from too frequent return to the same plot.

The combination of suitable forest management and a stable system of agriculture is a problem which arises in many parts of the world, particularly in areas with a dense native population with large requirements as regards local supplies of timber and fuel. In these conditions schemes such as the Village Forest Areas developed in Nyasaland may be suitable; the object of this particular scheme is to provide each village with an area of woodland, from which the natives may obtain a sustained yield of poles and firewood. There are indications that a maintenance of these communal woodlands will become a firmly established practice as the headmen perceive its value and the beneficial results which can be obtained with small expenditure of labour.

A particular problem of reforestation arises in connexion with the control of tsetse-fly in Tropical Africa. In the past it has been said that tsetse-fly control and erosion and flood control are antagonistic, because of the disastrous effects of widespread clearing of 'fly' areas in terms of accelerated soil loss and run-off. Extensive areas of bush and forests have been cleared in affected areas, particularly along water courses and around stock drinking pools, in order to permit the practice of animal husbandry with a reasonable degree of safety. Since the spread of the resulting erosion, special attention has been given to this question of clearing forest 'fly' areas; the late Dr. C. F. M. Swynnerton, of the Division of Tsetse Research in Tanganyika Territory, stated that 'wholesale clearing of thickets is not generally necessary; clearing should be extremely localized and discriminative, being based upon a precise knowledge of what the fly requires and of what are the least modifications that must be made in the forest if the insect is to be displaced'. By selective

cutting it may be possible to leave trees of a certain height or type without reducing the effectiveness of the control measures, and at the same time to do much to conserve the soil and water of the area. Owing to the different habits of the fly in different areas and at different altitudes, such selective cutting will require a very specialized knowledge on the part of the tsetse-fly controller.

We now come to the questions of treatment of degraded forest lands and of the reforestation of deforested areas. The most important aspect to be considered in any forest reclamation is the economics of the operations. The fact that land may have to be retired from cultivation, grazing or grass burning prohibited, or fuel and timber cutting reduced immediately introduces a number of economic problems. In addition, the economic yield from afforested lands is often low, although something can be done in certain cases to increase it. Reforestation must, therefore, be largely the concern of government or state bodies. Interest in tree planting can be stimulated by propaganda, particularly where some benefit to the population or the farm land might result.

In degraded forest areas a choice has to be made between reclamation by ecological methods, or by reforestation. Where misuse has not been so excessive as permanently to damage the forest vegetation, enclosure of the area can do much to encourage the natural ecological succession towards the climax type, particularly in more humid climates. It is necessary to prohibit grazing, burning and cutting. Regeneration of the tree flora, especially in more arid areas, may possibly be accelerated by a certain amount of engineering work, such as contour furrows, gully control and damming. Striking success is reported, for example, from the use of a system of contour channels for arresting the run-off in the poor, open, decrepit forest which covers the hills in what was formerly known as Chota Nagpur in the old Bengal Province. By encouraging the water to percolate into the soil instead of running to waste, remarkable growth is already being obtained in areas where formerly hollow, stag-headed, drought-stricken trees prevailed; blanks are filling up with regeneration and the density of stocking is increasing. These operations are cheap and the results are of considerable

importance, both for Bihar, where five-sixths of the forest is of this worthless type, and also for other parts of the world similarly affected. Although this work was begun only in 1933, the construction of contours on steep slopes to catch and hold water for the use of tree seedlings is reported from the Punjab as far back as 1880. It is also probable that enclosures and protection from fire and grazing will do much to revive the forest areas of West Africa which have degraded as the result of excessive shifting cultivation and too frequent return to the same area.

Where the type of tree characteristic of a particular locality has not great powers of regeneration, or again where conditions are too arid to permit the natural revegetation to proceed sufficiently rapidly to meet the requirements of soil and water conservation, artificial reforestation becomes necessary. It is difficult to generalize upon this question, as conditions vary so widely in different parts of the world. Reforestation may be intended to provide a permanent cover where it is required for protective purposes, or it may be adopted to give a forest cover for a given period of years only. Deforestation will then be carried out and the land used for agriculture again, but with the reservation that all the principles of a conservation agriculture are to be introduced in order to avoid a repetition of the soil deterioration which made the reforestation necessary.

The methods of reforestation based on the silvicultural (forest management) practices developed in Northern Europe cannot be applied with great success under widely different conditions, for example, in the countries bordering the Mediterranean. In order to study the particular problems of these countries, therefore, an association, 'Silva Mediterranea', has been formed, from the experiments and experience of which much valuable information should be derived.

The development of an adequate reforestation technique suitable for regions with a hot and arid climate has been discussed by A. Pavari[1] and other Italian, French and Spanish foresters. The Allegretti system which has been developed for these conditions depends upon the thorough cultivation of the soil to eradicate the useless bush and shrub cover (the *macchia*); the

[1]*Experiments and Investigations on Reforestation Technique in Regions with a Hot and Arid Climate.* Publisher, M. Ricci, Florence, 1930. (In Italian.)

new forest areas are created by sowing seed in this fresh environment from which root competition has been eliminated or greatly reduced. A. Merendi states that this method may be quite suitable on level land or gentle slopes, but on the steep slopes erosion would be severe, the bare soil being exposed to the elements until the forest vegetation became established. As an alternative the terrace or *gradone* method is recommended, as applied over thirty years ago by Montanari in the province of Aquila; this forester created magnificent black pine forests on calcareous soils, which by their aridity and lack of fertility are very hostile to arboreal vegetation. The width of the terraces as now used varies with the steepness of the slopes; the upper surface slopes inwards towards the slope, to an extent of not less than 30 per cent. These terraces are therefore equivalent in their action to contour furrows, collecting any soil washed from above and guiding the rain-water into the soil, instead of down the slopes, to the benefit of the vegetation. The terrace method may be replaced by the 'pit' method on better and more stable soils where droughts rarely occur. It is claimed, however, that for steep denuded slopes in droughty areas, the terrace method is the only one which can be used to create a new protective cover of forest. The method is being used in the vast reforestation work which has been executed by the Forestry Militia in Central Italy.

Apparently the sowing of tree seeds on level ground or in terraces is not extensively used elsewhere, the more usual system of transplanting seedlings from a forest nursery being adopted. The species selected depend upon the locality and the proposed utilization of the forest. Where a protective forest of an indigenous type is required, but cannot be grown from seed or established by planting, as in parts of South Africa, temporary plantations of eucalypts and pines may be made, in which the indigenous forest may regenerate itself. When exotic trees are used, however, there is a danger that the loss of water through transpiration (the giving off of watery vapour from stems and leaves of plants) may be so great as to have a serious effect on the water reserve of the soil. This has actually occurred with eucalypt plantings in South Africa. There is much scope for research on the diverse uses of trees and for the development of

new industries which will increase the economic return from reforestation schemes.

Trees also play an important part in the development of a conservation agriculture on cultivated land or pastures. The protective and ameliorative properties of a shelterbelt of trees may be very considerable. The use of trees in arid, semi-arid and other lands as protection against high winds has been known for some time. The best-known modern example of shelterbelt planting is the scheme inaugurated by President Roosevelt for tree planting in the Great Plains, a scheme which received much rather misguided publicity in the press.

The first recorded planting of trees for shelterbelts in Russia was made in the early nineteenth century by German farmer immigrants who settled in the steppe region north of the Crimea. Again between 1880 and 1886 many plantings were made, on such a spectacular scale and with such excellent results that a special government commission was appointed to study afforestation of the steppes. Nine objectives were placed before the commission, namely: (1) protection of farms from wind, (2) aid in ripening grain, (3) decreasing evaporation, (4) more uniform distribution and retention of snow, (5) raising the water-table, (6) decreasing the range of temperature fluctuations, (7) the attraction of rains, (8) raising the productivity of waste unused lands, and (9) the control of soil erosion and drifting sands.

Although some of these objectives have not been realized, at least six of the original large and numerous plantings still stand, having been maintained more or less continuously as experiment stations. The interest in shelterbelts lagged, however, until 1921, when planting was revived in the grain-producing regions subsequent to the severe famine of that year. Later the establishment of 865,000 acres of shelterbelts was planned in the second five-year plan, as compared with the maximum of 1,282,000 acres in the United States, planned to be spread over ten years.

The results obtained in the Russian steppes are indirectly applicable to the shelterbelt areas in western Canada and the United States. Data are available on the lay-out of shelterbelt areas, dimensions and spacing of units, density of planting and specific composition, combination of shrubs and trees; also, the preparation of sites for planting and the general silviculture of

shelterbelts. Under the rigorous conditions of Canada, Russia and Hungary, reliance is chiefly placed on indigenous trees. However they may be explained, the Russian data from observations on wind velocity, humidity, evaporation, soil moisture, soil fertility and even precipitation are said to give much support to the ameliorative value of a shelterbelt.

The planting of shelterbelts, inaugurated in the United States after the great drought of 1934, is being carried out within a zone 100 miles wide extending through the prairie-plains region from the Canadian border to the Texas Panhandle. This project was started in the face of amazing misunderstandings on the part of the public at large, who were led to believe that a solid belt of trees, 1,000 miles long by 100 miles wide, was to be planted from Canada to Texas, either to abate the winds or increase the rainfall in the mid-western States. Although, under certain conditions, the planting of solid belts of forest may have some effect on the precipitation, or possibly upon the efficacy of the rainfall, this was not the purpose of the American shelterbelt project. Shelterbelt management is only one phase of Plains management, developed in harmony with the entire land-use pattern of the region, and to be considered as part of a comprehensive programme of agricultural conservation. The inauguration of a special Great Plains forest experiment station to study various aspects of the problem was authorized by Congress in 1936.

According to Woodbridge Metcalf, windbreaks probably receive most intensive attention in the citrus region of California. With a bearing orchard worth up to $5,000 per acre a considerable amount of money can be spent on windbreaks to protect the trees from high winds. It is said to be economic to devote 10 per cent of the orchard area to windbreak trees and to spend $15 per orchard acre on windbreak maintenance. Windbreaks give effective protection if planted 300 to 400 feet apart. Wood lattice frames have recently been adopted for protecting new orchards, especially while the windbreak trees are becoming established.

In the semi-arid southern regions of the prairie provinces in Canada, shelterbelts are also being used and valuable data from research are being obtained at the Soil Research Laboratory, Swift Current, Saskatchewan. For example, a double row of

spruce trees, 25 feet in height, reduced the velocity of the wind for a considerable distance on the leeward side; even at a distance of 200 feet the velocity had been reduced by 50 per cent and the retarding action was noticeable to over 400 feet. The effect of this shelterbelt on evaporation was not so marked as on wind. In another case, the effect of a four-row belt of the Russian caragana and maple, running north-south with a crop growing to the east of it, was to increase the yield of a wheat crop for a distance of 150 feet into the field; this was due to increased moisture resulting from snow accumulation, and not to any particular protective effect of the trees upon the crop.

Although the establishment of trees and shrubs in these arid and semi-arid grassland soils of Russia and North America necessarily presents certain difficulties, these are being overcome, to the lasting benefit of the crop lands and the morale of the dweller on plains or steppes.

The tree species used in shelterbelts vary widely, but representatives of the native flora are usually included. In Canada, plantings are made of caragana, Manitoba maple, green ash, American elm, native white spruce, Colorado spruce and Scotch pine. Farther south in the American Great Plains, a wider range of species, including poplars, willow, elm, ash and pines, may be used. In most plantings an admixture of smaller trees and shrubs is necessary, at least on the edge of the belts, to act as a sand trap or otherwise to protect the ground around the taller trees. In other countries the species are *Cassia siamea* and other types including eucalypts in Tanganyika, acacias, casuarinas, eucalypts in Western Australia, and eucalypts and poplars in the Canterbury Plains, New Zealand.

The technique of shelterbelt planting under European temperate conditions has been highly developed in Denmark, where the full power of the winds from the North Sea causes serious damage to crops and sand-drifting in the low-lying peninsula of Jutland. It is considered that shelterbelts give protection to an area equal to ten to twelve times their height; favourable effects are claimed upon air and soil temperature, wind velocity, evaporation, relative humidity of air in local areas, and increases of yields of up to 30 per cent for some crops are obtained.

Finally, the conservation forester has to consider the many

other applications of trees and shrubs, such as their use in gully control, and for wild-life refuges, the planting of fodder trees as a reserve in times of drought, as is done in South Africa, either in the form of shelterbelts or farm woodlands, and the incorporation of trees in a highway planting scheme, along the lines developed in Germany with fruit trees and in France with the characteristic poplar avenues.

CHAPTER XIII

Dust, Dunes and Deserts

Desiccation induced by man. The sandy deserts of Turkestan. African deserts. Advance of the Australian desert. The American Dust Bowl. Deterioration rapid, regeneration slow. A problem for the ecologist. Desert reclamation in the U.S.S.R. Drift sands in Hungary. Regulation of grazing, crop cultivation and reforestation on the desert fringe in Africa. Land utilization in Northern Nigeria. The transformation of the Kalahari. The Namib Sand desert. The future of pastoral settlement in the semi-desert belt of Australia. Americans use wind to reclaim eroded land. Soil drifting in the Great Plains and Prairie Provinces. Dry-land agriculture. Dust the despair of the housewife. Control of soil drift. Dry-land strip farming. Listing and basin listing.

Much concern is being expressed in different parts of the world on the threat of the desert, in those 'regions of aridity and desolation where', as Dr. W. C. Lowdermilk writes, 'the recklessness, ignorance and hunger-drive of man have supplemented the process of wind and water erosion in destroying vegetation and soils, resulting in regional suicide'. The encroachment of sand from a central desert already in existence upon formerly valuable and fertile country has a spectacular news value, especially if coupled with theories of major climatic changes, beyond the control of man, which are favouring the growth of deserts.

The history of civilizations is a record of struggles against the progressive desiccation of agricultural land, but this land was reduced to a state of desolation and poverty by the hand of man more than by climatic change. This man-induced desiccation is still proceeding at the present day in that zone of delicate ecological balance between the humid and the true desert climates which occurs in many parts of the world. The deserts of Soviet

Central Asia are threatening the irrigation systems of the fields and gardens which lie along the river valleys. The Sahara is being augmented by large areas of recently denuded and desiccated land on the south and south-west towards Nigeria, the Gold Coast and Sierra Leone, on the north-west to the foot of the High Atlas, on the north to Libya, and on the south-east towards Kenya and Uganda. The great Australian desert is being extended in the zones where it meets South Australia, New South Wales and south-western Queensland.

The sandy deserts of Turkestan have been used as pastures for a very long time, particularly for Astrakhan sheep and partly for camels. Of the great flocks of sheep in south-eastern Kara Kum, which formerly supplied Bokhara with hides to the value of fifteen million roubles, only a small part remains, owing to the overgrazing of the scanty vegetation of the deserts and the areas bordering them. The advancing dunes, no longer bound by the peculiarly adapted vegetation, threaten the populations in the oases and narrow river valleys and each year bury large areas of highly fertile irrigated land. The extension of cattle raising planned since the revolution is likely to add to the denudation, unless the measures now being taken produce their effect. The saxaul forests of Turkmenistan, representing the final stage in the ecological succession on the sands, are the best means of binding the sands but they also provide the natives with valuable fuel. The exploitation of this resource has led to the loss of the capacity to regenerate, with the result that the sands deprived of their cover begin to move with the wind and threaten the Turkestan railway.

Professor E. P. Stebbing has written extensively on the threat of the Sahara and the man-made desert in Africa. In West Africa, the process of sand invasion or encroachment is considered to be due primarily to the practice of shifting cultivation, as the method of farming the bush or degraded types of forest characteristic of the transitional zone. With an increasing and more settled population the same areas are farmed again at shorter intervals, with a consequent more rapid deterioration of the fertility. When the soil is no longer suitable for cultivation, it is used for stock-raising, first cattle, then sheep and goats as the vegetation becomes poorer. Under the final excessive graz-

ing, browsing and annual firing, the 'savanna succumbs and the desert has encroached and extended its boundaries' (Stebbing). In other words, although the misuse of the fringe of the desert has caused the transitional zone to become desert, it is not correct to say that the desert has 'advanced'. The soil of the degraded land becomes covered with a sandy upper layer, gradually increasing in depth. This layer is presumably the result of decomposition of the original soil and not an accumulation of sand brought from the adjacent desert by wind action.

In a study of the arid regions of Northern Nigeria and the French Niger Colony, F. S. Collier and J. Dundas doubt whether there is, as has been claimed by some, a natural process of desiccation or an actual encroachment of the desert to explain the deterioration of conditions which has occurred. The extent of the Sahara has fluctuated in the distant past with oscillations of the world's climate; there has been severe desiccation in the prehistoric past, but the present climate is more humid than that of the immediate geological past. 'The western Sahara is a region of closed drainage, a natural sink, and, even with a stable climate, conditions in such an area might be expected to deteriorate rather than improve, owing to river capture on its outskirts, flooding and induration of the soil, progressive silting up of drainage channels, with consequent progressive loss of water by evaporation, the flooding of new areas and drying up of others.'

Collier and Dundas consider, however, that there is good reason for anxiety. The region has always been a potential famine area, with a soil most susceptible to damage by over-utilization and by the unrestricted action of water and wind. The rainfall is barely adequate for agriculture. Soil impoverishment is becoming formidable, deforestation is proceeding at an unprecedented rate. The conclusions of a more recent Anglo-French survey of the fringe of the Sahara are quoted on p. 74.

According to F. N. Ratcliffe, erosion and soil drift have occurred in the 'bush' country (saltbush shrub steppe) of South Australia, in the arid pastoral areas which receive an average annual rainfall of less than ten inches and are devoted almost exclusively to sheep. Erosion in such country usually liberates only a relatively small amount of surface drift, but this is very

destructive to seedlings; the 'bush' cover is thus replaced by shorter-lived species. More serious drift follows the erosion of light sandy soils. The fact that rabbits prevent the natural regeneration of many species of trees and shrubs, especially *Acacia aneura*, the mulga, is considered to be a cause of loss of stability of the sandhill country, which may ultimately result in the reversion of great areas of 'scrub' country to sandy desert.

The man-made desert in the United States, the now famous and possibly exaggerated Dust Bowl of the States of Texas, Oklahoma, Kansas and Colorado, is not directly comparable with the foregoing examples. It is not a transitional zone on the fringe of an existing desert, but was brought to an almost desert-like state by over-cultivation of the original semi-arid grasslands, much of which should not have been ploughed in the first place.

The rehabilitation of these great areas of degraded and deteriorating sub-desert lands presents many characteristic problems, some of which must inevitably be incapable of solution. The process of deterioration may become so rapid, and that of rebuilding the original vegetation so slow, that the problem is extremely urgent wherever it arises.

The reclaimer of man-made deserts has to become conversant with the stages in the ecological succession of the vegetation, both towards the complete desert, and, on the up-grade, towards the best protective vegetation which can be obtained under the circumstances. He must also study the regeneration of the soil from its useless state as sand or dust. As emergency measures, he must be able to fix or otherwise control isolated drifts in agricultural land and erect temporary protections for irrigation channels and other works. Other problems indirectly connected with the above are concerned with the fixation by sand-binding plants of the dunes on sea-coasts and lake shores, which may become dangerous if the prevailing wind causes them to move towards adjacent agricultural land. Much has yet to be learnt regarding the regeneration of the desert fringes before the principles of a new agricultural system directed towards the conservation of the soil and vegetation at their highest possible forms of development can be laid down. Possibly in the fundamental study of desert and semi-desert ecology

and reclamation the Russian workers are leading at the present day.

The Bureau of Deserts of the U.S.S.R. Institute of Plant Industry is making a special study of the reclamation of all the Russian deserts, of which the largest area occurs in Central Asia. It is stated that from three and a half to four million hectares can be reclaimed sufficiently to permit the cultivation of specially adapted crops and vegetables, while another nine to ten million hectares can be improved to such an extent as to provide grazing for both cattle and sheep under conditions which must be strictly controlled, because of the unusual environment. The work is being carried out on the edge of present settlements and along river courses, where the irrigation systems will acquire protection through the fixing of the dunes with vegetation and the increase of the improved agricultural land along the edge of the dunes. The pioneer plant on these Russian sand dune areas (barkhans) is *Aristida pennata* var. *Karelini*, a large sand grass which can stand being covered almost to the tip and has the faculty of growing through the sand; its rather coarse forage is used for pasture or as hay for winter feeding of cattle. The forage resources of the barkhans are poor in quality and quantity, however, and they have been utilized up to their limit in the past, partly owing to the fact that a high water-table (level of underground water) supplies abundant water for stock. The wells occur at a distance of three to four kilometres from one another, and the stocking rate is about one to three hundred sheep per well.

Experiments in recent years in U.S.S.R. have proved the possibility of cultivating land which had previously been considered unsuitable for agriculture. For example, experiments in the Kara Kum desert during the past four years have shown that these deserts are quite suitable for the cultivation of many plants, including mulberries. Specially resistant varieties of melons are grown by the nomads of the central Kara Kum, in the valleys and in the moving sands close to the subsoil water. It may later be possible to obtain two crops of melons in a year. Similarly, success has been achieved with the cultivation of lucerne, barley, rye and some fodder cereals; promising results have been obtained with the cultivation of grapes.

The problem of water supplies is an outstanding one in desert and semi desert areas. In Kara Kum it is planned to create new oases of a total area of about 10,000 acres, for which subsoil water will be raised by windmills and other means. It is not yet known whether the salt content of this water will be too high for agricultural use, as is the case in parts of Alberta. Under the very low rainfall conditions of the Central Asian deserts, any improvement in the vegetative cover means a greater drain on the ground water supply, with the result that the pioneer herbage may again become extinct, the vegetation proceeding towards the next stage in the succession, that of deep-rooted desert trees such as the saxaul (*Arthrophytum haloxylon*).

The afforestation of drift sands is also in progress in Hungary, in the vicinity of Kecskemét to the south-east of Budapest, where the rainfall is about twenty inches per annum and the summers hot and dry. An earlier scheme of afforestation was carried out on about 750 acres, principally with the black locust (*Robinia pseudoacacia*), but also with poplars, birch, alder and other trees. The Robinia succeeded only on the better sites, being replaced where it failed by Austrian pine. Natural regeneration is now being encouraged by the adoption of a selective type of felling in place of the previous clear-felling on a 30-year rotation. A close relationship has been established between soil quality and plant association, the types of associations depending partly upon the depth of the water-table and partly upon the composition of the sand. The seven vegetative types, ranging from the *Festuca vaginata* association to the *Festuca pseudovina-sulcata* association, may be linked up with the appropriate tree species. It is therefore now possible to select planting sites for *Robinia*, the grey poplar, the Austrian pine and the Scots pine, and the numerous other species which may be employed. A sub-association of the *Festuca subovina* characterized by the presence of *Fumana vulgaris* always occurs on soil very deficient in plant nutrients and therefore useless for afforestation. The chief practical difficulty in afforesting these drift sands lies in the very rapid variations in site quality.

An example of success achieved in the use of vegetation in the reclamation of coastal sand dune areas may be seen in the Landes de Bordeaux, where extensive pine forests were planted

many years ago to control the menacing sands between Bayonne and Bordeaux.

In Africa the problem is not so much the reclamation of deserts and sand-dune areas as the regulation of grazing, crop cultivation and deforestation in the desert fringe in such a way that the extension of the desert shall be prevented. The chief causes of the deterioration around the Sahara are the deforestation and soil impoverishment necessarily connected with the practice of shifting cultivation, particularly on the short-rotation 'bush fallow', the overstocking or improper stocking of the savannas and other grassland areas, the annual burning of the grass to provide succulent new growth for the stock or to assist the hunters, and the widespread and hitherto unregulated destruction of the forest and other vegetative cover associated with tsetse-fly control. In addition to the losses in crop yields and carrying capacity which these malpractices entail, the maintenance of a continuous and regular water supply and possibly also of a sufficient rainfall is a related problem of great importance throughout Africa.

Professor Stebbing compares the situation with that in India, where shifting cultivation and annual firing have to some extent been discontinued, and suggests that 'it is for the Administration to act', not through the slow process of educating the natives but by the introduction of measures directed towards the early removal of the adverse factors elaborated above.

F. S. Collier and J. Dundas discuss measures which may be applied in Northern Nigeria, these being concerned first with conservation throughout the region as a whole and secondly with the maintenance of the fertility of the farmlands while retaining them under crops. The problem confronting the French farther north in the Niger Colony is quite different, being concerned with the rehabilitation of a country which has lost its prosperity through a complete reversal of the flow of trade and the development of regions derelict from lack of population. In the arid regions of Northern Nigeria, 'measures for regional conservation involve the classification of land

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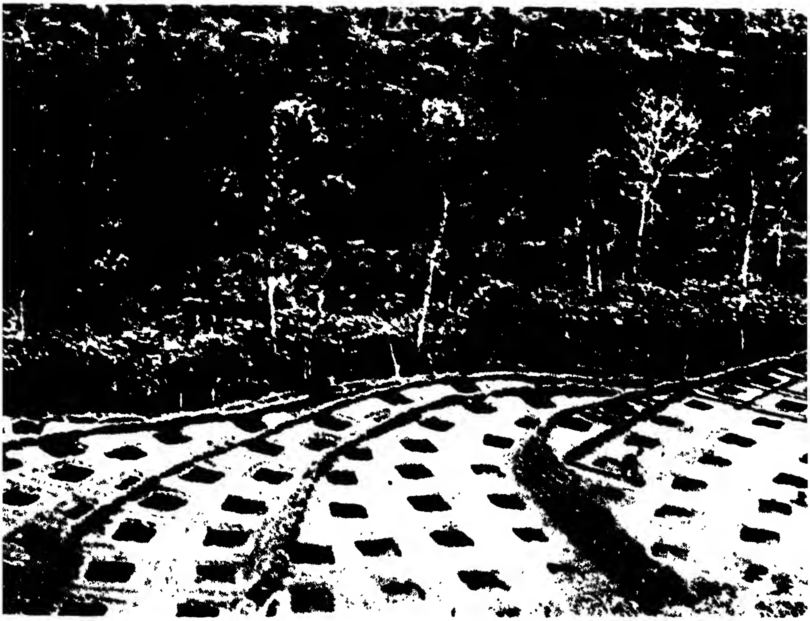
28. Java. Terracing and preparation of land prior to planting coffee. See page 136.



according to use and the provision of safeguards against its misuse. Protection is needed in the first place for areas where, in the opinion of geological officers, deforestation would bring about erosion, exposing the underlying rock of infertile subsoil and causing irreparable soil damage; or would result in loss of control of run-off in important catchment areas. It is further necessary to segregate those areas which, owing to lack of facilities for creating a permanent and adequate water supply, are impossible to develop into permanent farmlands. The Veterinary Department should determine what lands are necessary and suited to provide pasturage for the great herds of nomadic stock that contribute so largely to the wealth of the country, and, in an emergency, for the cattle which are essential in the farmlands for the continuance of permanent agriculture. And finally it has to be decided what areas should be allocated for the maintenance of essential supplies of fuel and forest produce for the lands under agricultural settlement.'

The practice of shifting cultivation can do no permanent harm to the soil provided that an adequate interval is permitted between each cropping. When the demand for land exceeds the safe minimum, it is essential that the bush-fallow system be replaced by a system of soil improvement, either with green manure crops or animal manure, the latter of which may entail the extension of mixed husbandry and fodder crop cultivation. The replacement of the bush fallow by manure is a requirement which has been realized in the well-timbered permanent farmlands of Kano. There is a possibility that the expansion of farming and the development of continuous cropping may be too rapid for the parallel evolution of better farming and manuring methods.

Afforestation in the farmlands of Nigeria is to be regarded as a last resort, apart from the planting of fruit and fodder trees and windbreaks. The necessary measures must be directed towards provision of the fodder for the stock essential for supplying manure, the creation and conservation of adequate

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29. Basutoland. One of 326 terraced gardens in the Maseru district. This widow built the seven terraces herself on the advice of the native demonstrator. See page 137.

water supplies and the maintenance of fuel supplies, all to be regarded as steps in the progress towards a balanced conservation agriculture adapted to the particular conditions of the area. 'Development must be considered as a whole, with the principle in mind that the greatest benefit to the individual is by no means invariably the greatest benefit to the community' (Collier and Dundas).

The problems in the other territories which fringe upon the Sahara vary in detail, but the same principles of conservation apply.

South Africa contains an example of the transformation of a vast desert, the Kalahari, originally composed of a regular succession of sand dunes, probably quite devoid of vegetation, into a savanna forest, a natural reclamation probably caused by a change of climate. The other great area of drift sand in this part of Africa is the Namib sand-desert in South-West Africa; it has been stated that this enormous area awaits a similar change of climate, such as a replacement of a cold current by a warm one in the southern Atlantic, before natural reclamation can occur. The aridity of the climate (1–2 inches precipitation per annum) together with the vastness of the area place artificial reclamation beyond human capacity. In addition to this area of five and a half million acres of steadily advancing sand in South-West Africa, there are some 90,000 acres in the Union, by far the greatest majority of these occurring in the south-western districts. This is in addition to about 27,000 acres which were reclaimed up to 1934.

The methods used for drift sand reclamation in South Africa are:

(1) the erection of barriers to arrest the inflow of sand at the origin of the drifts, or along their sides to stop lateral extension, at their ends to protect threatened vulnerable objects, or on the crests of individual dunes to prevent their moving farther, and

(2) covering the surface wholly or partially, depending on local circumstances or design of the reclamation scheme; this is secured by bushing either entirely or in layers or strips, or by planting or sowing grass or other pioneer vegetation;

(3) introduction of an arborescent crop permanently to stabilize the work. Permanent reclamation is impossible without

trees, as the grasses used are temporary; by stopping sand-movement they kill themselves.

The problems of the future of pastoral settlement in the semi-desert belt in Australia have been studied by F. N. Ratcliffe. In this low-rainfall country, except for certain grass-plain areas, edible evergreen bushes and shrubs form an important fodder reserve for stock in the recurrent drought periods. The deterioration of the desert fringe is due to the uncontrolled grazing of the valuable saltbushes and other drought-resistant shrubs by sheep, following overstocking and the subdivision of the land into areas too small to allow an adequate safety margin in drought years.

Any policy of rehabilitation in these areas of Australia is limited by the low value of the land. The possibilities of successful plant introduction and the utilization of native species for the stabilization of drift are slight, chiefly because of the climatic conditions. The stocking policy must be adjusted in equilibrium with the vegetation; nothing the botanist and ecologist may ultimately achieve can abolish the necessity of placing the stocking on a permanent and scientific basis. Investigations along certain lines are required, including a search for exotic sand-binding plants. The data obtained at the Koonamore Vegetation Reserve regarding the rate of spread of saltbush over a denuded area provide a fair indication of the slowness of the process. Even in a paddock three miles square and completely surrounded by healthy bush, there would be little hope of the re-establishment of a saltbush cover by natural seeding in less than twenty or thirty years, however favourable the conditions. Further, except in the case of small shallow drifts which can be distributed through patches of low-growing vegetation, drift sand in these areas will not be permanently stabilized as a result of the natural processes of ecological succession which operate to-day in the arid pastoral country.

A striking example of the utilization of wind action, the force responsible for the severe erosion damage, to rebuild a severely damaged area in the southern Great Plains of U.S.A. so that crops were produced at a profit within one year is provided by the work near Dalhart, Texas, under the care of C. J. Whitfield and F. C. Newport. In a field of 470 acres, first

cultivated in 1931, fifty-seven sand dunes were found in a survey in 1936. These dunes varied from one to nine feet in height and averaged 161 feet in length and 113 feet in width. The substratum around and between the dunes was hard and eroded to a depth of ten to twelve inches. The remainder of the field was hummocky. The entire area, including the dunes, was solidly listed in November 1936; the surface was left in a cloddy state, thereby catching the material which moved off the sand dunes, causing them to become smaller and filling the lister furrows with sand. Thus the damaged land was rebuilt, as within three months of the completion of the listing about 60 per cent of the material had been spread back over the field and the number of dunes had decreased from fifty-seven to twenty-nine. In the following summer a good cover of sorghums, Sudan grass and millets was obtained on this derelict field, which was thereafter reclaimed for agricultural use and no longer acted as a menace to surrounding fertile farmlands, pastures and buildings.

The examples which have been given are indications of the problems which arise when agriculture is carried to the fringe of the deserts. Deterioration can be very rapid when the delicate ecological balance of flora and fauna is disturbed by overgrazing or other misuse. When once such land is denuded, regeneration by natural means is generally slow, the opposite extreme to the conditions observed in the humid tropics. Reclamation of degraded semi-desert by artificial revegetation is in all cases difficult and in many cases impossible. The agricultural scientist is not yet qualified to recommend any definite practices for such lands, as he is for the new conservation agriculture of more humid regions. Where overgrazing is of more recent occurrence and has not been so excessive as to eradicate the grass vegetation completely, enclosure of the grazing lands, as in British Somaliland, for a period of a few years only will be of great benefit, the natural regeneration being rapid and striking. This serves to emphasize the urgent necessity for such action as enclosure, control of grass fires, provision of wells, better distribution of

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30. Illinois, U.S.A. Pair of photographs showing the Borgsmiller gully before and after planting with black locust. See page 141.

stock and other moves to relieve the vegetation from the strain which is being put upon it in so many parts of the world.

Another type of man-made desert requires consideration, namely, that of the Great Plains of the United States and the Prairie Provinces of Canada. In this great region of semi-arid grasslands, the virgin sward was ploughed up to grow wheat on the system which became known as dry farming, or dry land agriculture. The basis of this system is a rotation of grain crop and fallow, a clean cultivated fallow alternating with one or two years of wheat, on the assumption that sufficient moisture from the low rainfall would be stored in the soil during the fallow year to meet the water requirements of the subsequent crop. This type of agriculture has led to severe soil drifting in Western America and Canada, large amounts of soil being transferred for considerable distances in extreme cases in the form of dust storms or 'black blizzards'. The virgin soil is brought to a condition in which it will drift or blow by the breakdown of the original crumb structure and the decomposition of the fibrous root systems of the original grass vegetation. The fallow lands covered with this loose dusty soil are exposed to the action of the spring winds of the Plains and much damage is done.

Although the fundamental causes of soil drifting are not yet fully understood, they are obviously concerned with the action of wind upon loose, dry soil unprotected by vegetation (aeolian erosion). It cannot be said that the passage of high winds over dry bare soil necessarily leads to drifting; there are indications that there is a turbulence in the wind which has a lifting action upon the finer soil particles. Temperature may also have an influence, a change in direction of wind accompanied by a fall in temperature, but without any reduction in velocity, leading to a marked decrease in the severity of the drifting.

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31 *a*. Gully erosion in South Carolina. More than 40,000 tons of soil were washed from this gully in less than eight years. See Chapter X. 31 *b*. shows the same gully after reclamation. The banks were sloped in, black-locust trees, cereals and lespedeza planted, and the water diverted out of the gully at the head. See page 141.

No green manuring or application of organic matter in the form of farmyard manure can be adopted in a dry farming system. The former would remove the moisture required for the wheat; in addition, neither the green manure crop nor the organic matter would decompose under the low rainfall conditions, with the result that the cereal crop would 'burn' and no yield would be obtained. Although drifting is most extensive on summer-fallow land, it may also occur on land on which a regular rotation is adopted, given the proper combination of climatic conditions and soil.

Drifting does not arise spontaneously over a wide area, but tends to originate at certain focal points (blow-outs) from which it spreads very rapidly. These focal points are frequently on the tops of knolls or ridges or similar places where the soil is lighter and more easily blown.

Small local movements of drifting soil smother near-by vegetation, bury fences and block roadways. The larger soil particles have a cutting effect on tender plants, such as the stems of legumes. There can be no more desolate sight than a region seriously affected by soil drifting and blowing, and the effect upon the inhabitants is extremely depressing and demoralizing. All the soil may blow from the fields in a serious dust storm, farm buildings become smothered, water supplies choked and farm machinery buried. It is impossible to keep the fine dust out of the houses, as it penetrates through the smallest openings and gradually covers everything indoors, floors, furniture, bed and food, to the despair of the housewife, both on the farm and in near-by towns and villages. Breathing becomes difficult and painful and pulmonary disorders follow. Records taken of the number of dusty days at Goodwell, Oklahoma, during the five years 1933–37 give a good indication of the conditions; during the first four years there were 70, 22, 53, and 73 dusty days respectively, while from January 1 to August 1, 1937, there were 117.

The ecological balance of the original fauna and flora becomes disturbed, and pests have an opportunity to do damage. On grassland areas the superior grasses may be choked out by the dust or burnt up by the hot dust-laden winds. Shelterbelts, windbreaks and trees around the farmstead are smothered or

die because of the lack of moisture, due not to a lower but to a less effective rainfall.

Conditions such as these must be dealt with according to their severity. In badly blown farms at least temporary abandonment will be necessary until the land can, if possible, be revegetated and protected from wind action. In such cases it then becomes an economic problem; if an area is proved to be useless for further cultivation it must be put back to grass. This may not always be easy, as it is difficult to establish grass swards from seed under these conditions. The economic problem which arises if an abandoned farm can be regrassed is concerned with the proper utilization of such a farm subsequently. In many parts of the United States affected by wind erosion, the land was broken up into small farms which could be operated as economic units under wheat, but which are too small to provide an income with cattle, owing to the low carrying capacity of arid and semi-arid grassland and to the deficient water supply for stock. Measures are here necessary to increase the size of the farm, possibly by Federal purchase and subsequent lease or sale under covenants protecting its later use, or through extension of credit under suitable restrictions.

Some success has been obtained in artificial revegetation in the United States from planting small sods of buffalo grass, which spreads sufficiently rapidly to provide a ground cover and protection against wind erosion. Abandoned fields will revegetate naturally at a rate which depends upon the interval since they were first ploughed. The length of time required for the natural reclamation of abandoned fields by the more desirable grasses varies from twenty-five to forty years or more, depending upon the intensity of cultivation, degree and management of grazing, whether abandoned fields were enclosed and grazed with adjacent virgin pastures, proximity of tilled fields and pasture land, climatic conditions, soil blowing, topography, slope and type of soil. The plant succession on abandoned fields generally assumes four rather distinct but overlapping stages, e.g. (1) annual weeds and annual grasses, including the pioneer Russian thistle, (2) the less palatable short-lived perennial grasses and biennial and perennial forbs (miscellaneous plants), (3) short-lived perennial grasses, (4)

dominant and sub-dominant perennial grasses with other species.

In areas where blowing and drifting have been less severe, any recurrence of the removal of soil may be prevented by the adoption of certain agronomic practices intended to break up the amount of fallow land exposed to wind action in any one year (strip-cropping across wind), by growing cover crops which protect the soil at the dangerous periods of the year, to adopt such crop rotations as local conditions permit, by using methods of cultivation which will leave the surface of the ground in a rough cloddy condition and by planting windbreaks and shelter-belts of hardy trees where possible.

Strip farming does not appreciably alter cropping practices in a summer fallow-grain rotation, the fields merely being sub-divided into alternate strips of fallow or grain. Strip-cropping alone will not entirely control soil blowing, but it is very effective if combined with other methods intended to secure as much crop residue on the surface as possible, or with types of cultivation which maintain the soil in a lumpy condition. Where it is the practice to fallow every other year, alternate strips are laid down to spring grain; if the land is to be fallowed only once in three years, two strips are sown to spring grain and the third fallowed. Strips are usually laid down approximately at right angles to the most frequent winds. It is found, however, that strips actually give protection against winds coming from almost any angle; even if the wind is parallel to the strip, the damage is not likely to be severe as the soil on the strips has not been brought into a drifting condition by other winds. The width of the strips varies with the severity of the drifting; the practice in Western Canada is to make them ten to twenty rods wide although strips as narrow as five rods can be used on light soils. Some strips, e.g. in Montana, may be one or two miles long.

Strip farming has some disadvantages. The soil has a tendency to ridge at the windward edge of the stubble strips, a fault which may be overcome by proper cultural methods. Weeds such as Russian thistle tend to grow along the edges of the grain strips; grasshopper, sawfly and other insect pests may become serious under strip-cropping. Where extremely large cultivation and harvesting outfits are used, the farmers seldom

like to practice strip farming, but with ordinary power equipment there is little complaint, and the cost of operation is not appreciably greater on stripped than on unstripped land.

There is one serious criticism which may be levelled against the summer fallow-grain rotation system, even if strip-cropping and the other practices described below are carefully carried out. All these special measures are intended to offer protection to the *surface* of the soil against the action of the wind, but what of the soil itself? To the agriculturist more familiar with the aims and objects of crop rotation in more humid conditions, the fact that little or no organic matter, no green manure crop or even the valuable fibrous root system of a grass crop is returned to the land will appear to be very unorthodox. Organic matter or green manure cannot be added for the reasons given at the beginning of this chapter, but something should surely be done to incorporate the soil-binding grass root fibre in these arid areas. The only things that are returned to the soil in a dry-land grain-fallow rotation are the rather poor root systems of the grain crop and some crop residues, while even the weed growth is controlled by repeated cultivation on the fallow. Thus the soil passes further and further from its natural grassland type, presumably becomes more and more dusty and certainly decreases progressively in fertility. It is possible that, in very arid areas, where irrigation is impossible, a choice will have to be made between returning the land to grass, if this can still be established on the dusty soil and the introduction of a very drought-resistant grass into the rotation, alternating four to seven years with one to three years of wheat according to the severity of the conditions. The difficulty is to find a grass which can be used in these ways. Crested wheat grass may be used in very dry areas or brome grass in less extreme conditions, but no grass is known which can be established economically on drifting soil under Western Canadian conditions. Further south, Sudan grass, millets and sorghums may be used for this purpose. Possibly in Canada some of the new hybrids between *Triticum* species (wheats) and the grass *Agropyron*, i.e. the so-called perennial wheats, may be found to be of value for this purpose, particularly if large seeded varieties, which may be sown by grain machinery, can be developed.

The use of crop rotations which include grass and inter-cultivated crops may be employed to advantage in regions receiving adequate precipitation, or with a sufficiently favourable ratio between precipitation and evaporation. When using this method, the productivity of the soil is restored by ploughing in the organic matter or root fibre of a grass-legume mixture or a pure sowing of either.

Two methods of summer-fallowing have been developed on the Canadian prairie to control drifting. The more effective is the ploughless summer fallow, the basis of which is to keep down weed growth without burying the stubble or other trash in order that this material may provide a 'trash cover' on the surface as a protection against wind erosion. This method combined with strip-cropping effectively controls drifting, in addition to controlling weeds and conserving soil moisture for the subsequent grain crop. Special cultivating implements are necessary for this method, the one-way disk or the duck-foot cultivator being used in conjunction with a rod-weeder. A maximum of about four or five cultivations is sufficient to control annual weeds.

The other method of summer-fallowing is the ploughed summer-fallow. Land treated in this way is by no means immune to soil drifting, but on certain soils, ploughing at the proper season to a depth sufficient to turn up some firm soil to form a cloddy surface, followed by very little cultivation to control weed growth, is a reasonably safe practice.

Cover crops, consisting of a late summer seeding of spring grain, may be used effectively where a fair rainfall is received. Where the growth is good, some autumn pasturing may be obtained without affecting its protective value.

Another cultivation practice of great value in preventing soil drift and blowing, but more particularly in conserving moisture from rain or snow, is that of ridging or listing the land (Figs. 43 *a* and *b*), with special machinery adapted for the purpose. The particular merit of basin-listing in the collection and storage of moisture is obvious. This practice is used extensively in the arid Great Plains of the United States, and also, according to Dr. L. Dudley Stamp, in West Africa; here, however, the natives have not the advantage of the special types of

basin-listers which have been developed in the United States to throw up the dams within the rows. After listing, the land may be levelled before sowing or the grain or corn may be sown in the hollows between the ridges, thus gaining some protection and concentration of moisture until the plants are well established.

Proper methods of summer-fallow and crop rotations provide excellent control for many insect pests, in addition to the advantages already noted, but the incorrect use of these methods may seriously aggravate the situation. Where one or more insect pests are likely to cause economic crop losses, the recommendations for the control of soil drifting must be adapted to meet these insect problems.

Under suitable conditions, also, windbreaks composed of hardy drought-resistant trees may be planted at intervals between the strips, thereby breaking the full force of the wind and giving some protection to the crop between. This question is considered more fully in Chapter XII

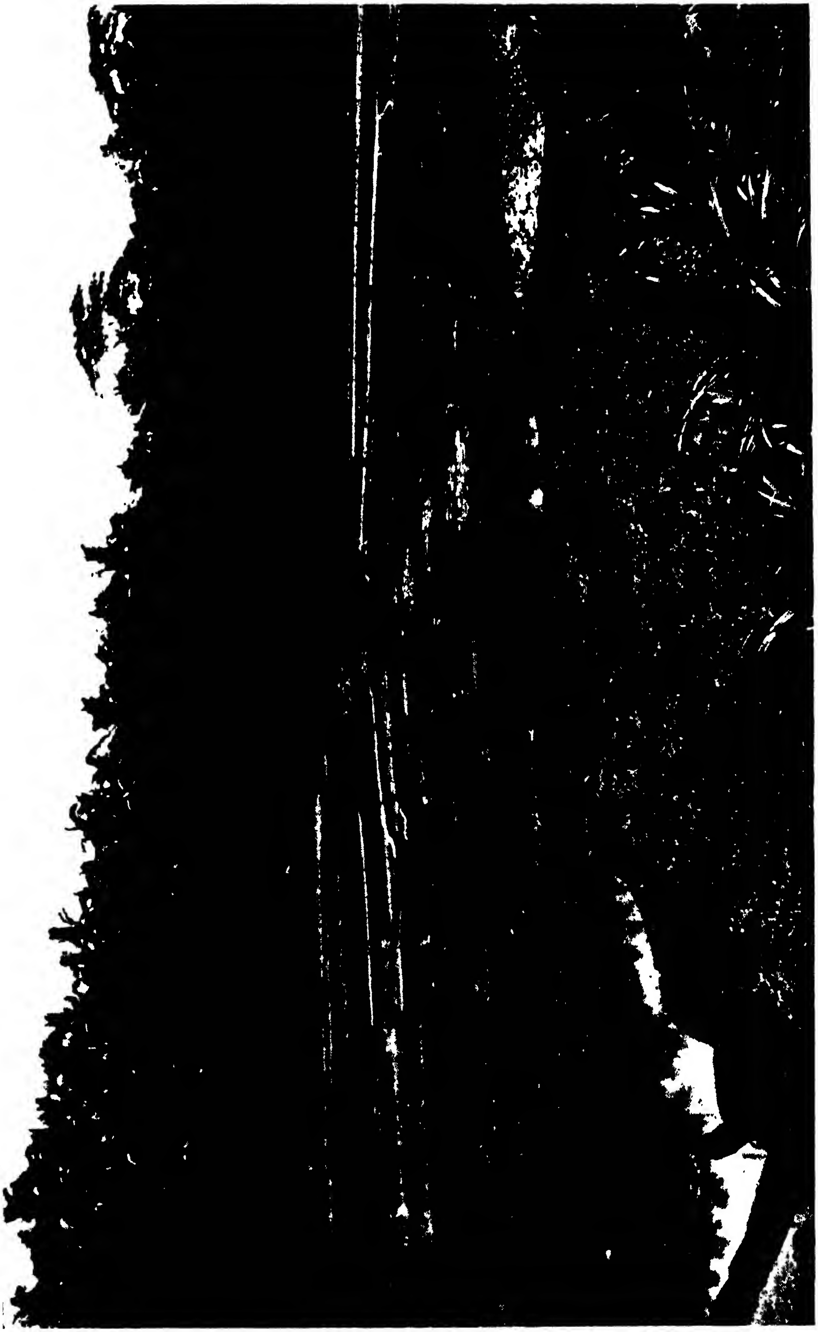
CHAPTER XIV

Water Conservation and Flood Control

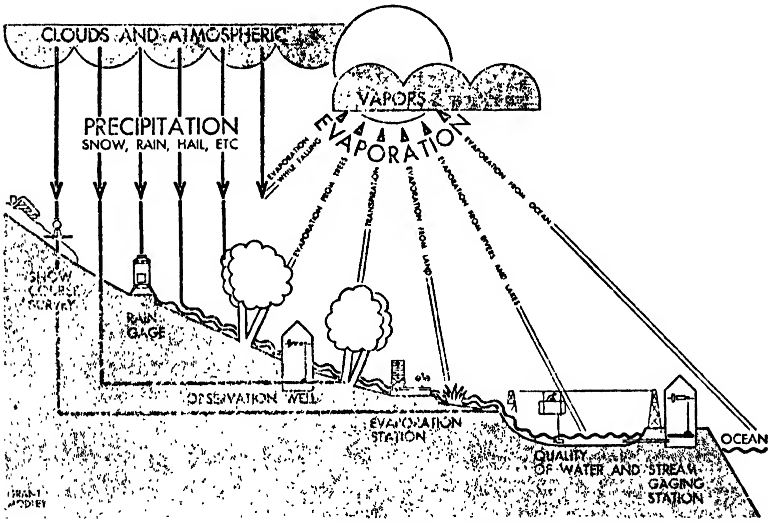
Downstream versus *upstream flood control. The hydrologic cycle. Conserving run-off in the headwaters. The economics of upstream control. Upstream reclamation, surface run-off and storage in the underground water table. Siltation of reservoirs and irrigation systems. Requirements of upstream and downstream inhabitants and industries must be considered jointly. Water conservation on semi-arid lands. The basin lister. Trenches for reforestation. The water supplies for irrigation. Much still to be learnt about water conservation and the hydrologic cycle. The ground-water resources of East Africa.*

The average man thinks of flood control as entailing the construction along river courses of protective walls, earth embankments or levees. He thinks of water conservation as the storage of reserve supplies in reservoirs for human use or the guidance of streams in aqueducts for use in driving power plants or for irrigation schemes. A river, however, should not require to be embanked excessively to control floods. In course of time it will erode its own bed through the plain to a depth sufficient to keep the waters between the banks, except under very abnormal conditions of flow. But when eroded soil from upstream regions fills the bed in the plains, and excessive run-off from eroded land makes the once abnormal flows normal occurrences, an artificial and dangerous passage for the river has to be built above the level of the plain. Costly and seldom fully effective 'downstream' flood-control works, which do not touch the cause of the flood, have to be constructed because 'up-stream' engineering—the prevention of the excessive run-off and erosion which cause the floods—has been neglected.

32. Java. Reclamation of ravine by construction of rice terraces. See Chapter X.



All patterns pertaining to upstream engineering depend ultimately upon the hydrologic cycle, i.e. the movement of water as it relates to the earth. Hydrology cannot yet be called a science, firstly because of the great complexity of the hydrologic cycle, and secondly because of the lack of adequate observational data which may be used to produce accurate scientific deductions. The major elements in the hydrologic cycle are clearly indicated in the diagram presented below. This may suggest that the



The Hydrologic Cycle, from Headwaters, Control and Use

cycle of precipitation, infiltration,[1] run-off, evaporation and condensation to precipitation again is an obvious and simple sequence of natural events. Although all the factors are known, little is known about their interrelationships, and the facts

[1] Passage of water down through the soil.

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33 *a*. Bisect showing relation of roots and tops of grasses and forbs in a typical short-grass area in West Central Kansas. Note the very definite root layer formed by the grasses and the deeper one by coarse forbs. 33 *b*. Bisect showing relations of tops and roots of grasses and forbs typical of the big bluestem type of prairie in West Central Kansas. See page 145.

which are essential in the coordination of different systems of land and water use. It is obvious, however, that flood control is as much, if not more a matter of the headwaters and their control than of the erection of enormous protective structures in the lower reaches of the rivers.

Probably in few cases where floods now occur will it be possible to dispense with downstream engineering works, at least for some considerable time to come, but the value of these works in their present state can be greatly increased by the adoption of all possible conservation practices in the headwaters. The water which accumulates in streams and rivers may arrive in two ways, either as surface run-off or from the ground water-table in the form of seepage water or springs. It is obvious from the frequent references which have been made in the foregoing chapters to the measures which can be adopted to control excessive run-off that, in spite of the complexity of the hydrologic cycle, something can be done under most circumstances to influence the amount of run-off water which passes direct into the rivers, frequently causing them to flood. Other references have already been made to the action of forest or grass covers in guiding rainwater safely to the underground storage, from which it reappears over a considerable period from springs and seepage, maintaining a steady supply to the river in place of the sudden rush of run-off water which follows an excessive downpour on a non-retentive watershed. The adoption of cultural and other practices to reduce run-off and soil wash and the maintenance of a good vegetative protective cover are the bases of effective upstream engineering in any part of the world. The reduction of run-off will mean that more water is passing into the soil and to the water-table, that streams will have a steadier supply; the vegetation which facilitates this transit generally itself benefits from the higher water-table, at least in semi-arid climates, and thus the vicious cycle of denudation, erosion and flood changes to the beneficent cycle of revegetation, water storage, soil retention and reduction in the number and height of floods.

The processes of degeneration in a watershed or catchment area, resulting from excessive clearing, burning or overgrazing, may result in flood damage in a very short time, whereas the processes of regeneration are slow, the rate of revegetation de-

creasing with an increase of the period since the denudation began. Thus again we must conclude, as we have already stated in the chapter on the advance of the desert, that the urgency of the commencement of reclamation work in affected watersheds and catchment areas cannot be over-stressed. It is not necessary to quote examples, as the problem arises in all countries suffering from erosion, whether temperate or tropical, arid or semi-arid.

The first step (following a survey of the conditions in any particular watershed and catchment area) is to stop the type of misuse of land which has caused the trouble, whether this be deforestation, fire, overgrazing or excessive cultivation of steep slopes. This immediately brings in the economic factor. The area to be treated may be far from any town or other community and may be quite uninhabited, except for the tree fellers or graziers, or it may contain settled agricultural communities whose land-use system may be difficult to change without an economic upheaval. Large valley communities or industries may willingly undertake colossal schemes to counteract floods and prevent damage to their interests in the actual valleys, but the little waters in the upper part of the watershed have been considered to be beyond the scope of their activities. When the conservation operations are commenced upstream, they must necessarily be simple and inexpensive. Even so, in the analysis of costs and benefits, the technique for measuring expenditure and receipts employed by private industry is inadequate for calculating the cost of conservation works for three major reasons. 'It seldom takes into consideration: first *multiple* uses and benefits; second, *intangible* uses and benefits that cannot be measured in terms of money, and sold; and third, costs or losses that are being experienced and will continue to be experienced if the contemplated measures of conservation are not pursued. Social accounting is quite a different order of accounting from that employed by private industry. Private accounting is the accounting of acquisition and the preservation of ownership; social accounting is the accounting of the satisfaction of need and the prevention of losses of human and physical assets' (Morris L. Cooke, Rural Electrification Administration, U.S.A.).

In a watershed or drainage basin which has been deforested

by tree cutting or burning, a certain percentage of the area should be reserved, particularly on the steeper slopes and along the stream banks. If the damage has been severe and natural regeneration is slow, some planting operations may be necessary, with possibly the construction of contour ditches to guide the water into the soil. Where the cost is justified, these contour ditches or furrows on forest or range land are built to a capacity calculated to retain the maximum rainfall per hour known for the locality. If erosion has already been serious, a certain amount of gully control may be necessary. Overgrazing or firing of grassland or pastures must be prevented, and the rested vegetation will receive much benefit from any system of contour furrowing which may be adopted.

Some of the cultivated land may have to be retired from production, while on the remainder the various practices for conserving moisture described in Chapter IX will be necessary. In particular, the simpler of these, such as contour cultivation and planting, strip-cropping and so on, are specially applicable to the upper regions of the drainage basin. As one proceeds downstream and the land becomes more valuable, the more elaborate methods such as terrace construction can be used economically.

With the adoption of these simple practices in the upstream reclamation work, the amount of surface run-off will be greatly reduced and the amount of water added to the ground water-table greatly increased. A proportion of the surface run-off may be safely stored by the construction of small, inexpensive dams, but the storage of the underground water-table is much more important. A member of the Tennessee Valley Authority has stated that if the water-table of the Tennessee Valley could be raised only six inches, it would mean the additional storage of 26,000,000 acre-feet of water, four times the capacity of the Norris reservoir.

The passage of more of the rainfall to the underground stores means that there is less surface run-off to find its way direct into

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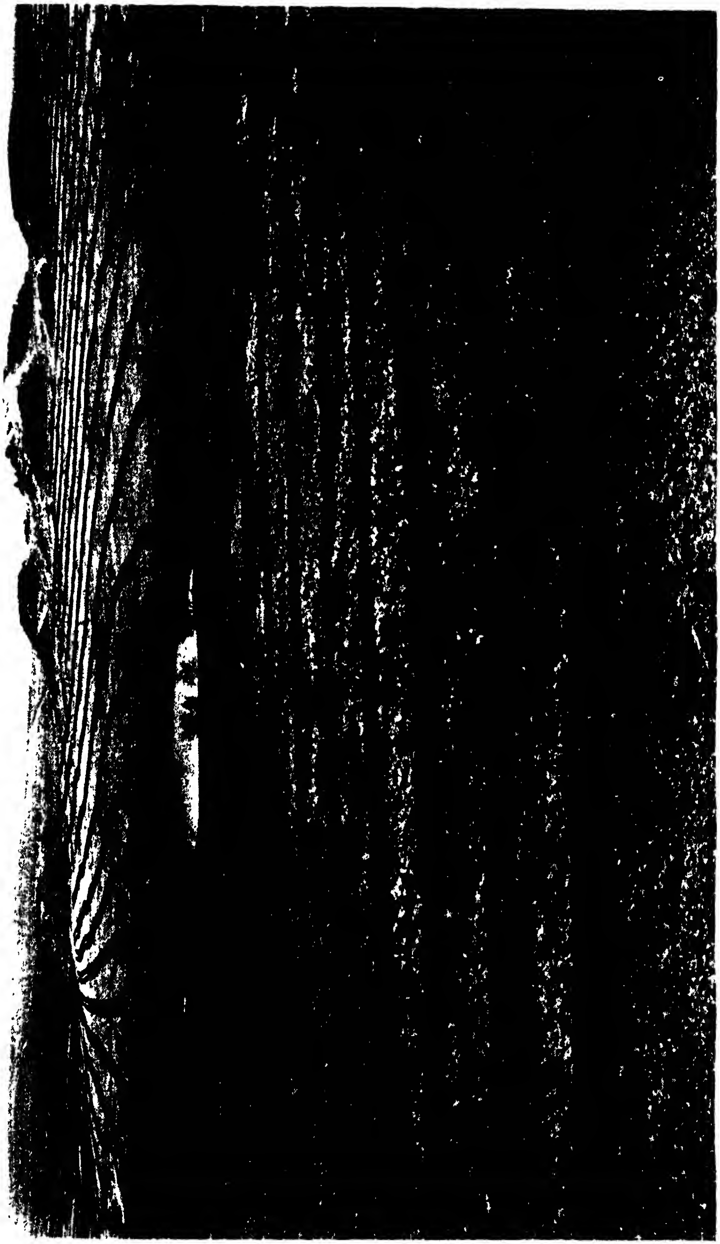
34. Texas, U.S.A. Pasture furrowing. Lines run at horizontal intervals of approximately thirty feet; two furrows are made on each line with a six-foot spacing of the furrow. See pages 149 and 150.



the stream or river and that the reduced run-off has less power to erode and acquire a load of silt to be carried to the river. Instead of depending upon the unreliable rise and fall of surface water supply, which varies with the frequency of the rainfalls, the river receives a much more stable and reliable supply from the springs and seepage waters fed from the underground water-table.

TABLE 3. MATERIAL CARRIED IN SOLUTION AND IN SUSPENSION BY AMERICAN RIVERS[1]

River	Location at which samples were collected	In solution, parts per million	In suspension, parts per million	Solids per square mile, tons
Mississippi	Minneapolis, Minn.	200	8	6
Mississippi	Jefferson Barracks, Mo.	206	964	250
Missouri	Kansas City, Mo.	426	2,032	286
Ohio	Cincinnati, Ohio	120	230	363
Tennessee	Gilbertsville, Ky.	101	127	200
Arkansas	Little Rock, Ark.	630	748	145
Kennebec	Waterville, Me.	48	4	7
Susquehanna	Williamsport, Pa.	74	18	30
Colorado	Austin, Tex.	231	351	26
Colorado	Yuma, Ariz.	710	5,354	387
Rio Grande	El Paso, Tex.	700	14,140	418
St. Lawrence	Ogdensburg, N.Y.	134	Trace	1

The silt load carried by rivers is an important aspect in any conservation programme (Table 3). The run-off water from an eroding area of land carries with it a load of silt in suspension, which is not deposited completely until the velocity of the stream flow is reduced by a reduction in gradient. There are innumerable examples in the United States of the complete silting up of lakes (Figs. 41 *a* and *b*) and reservoirs, some of which were constructed at enormous expense and were intended to supply large

[1] Bennett, H. H., U.S. Dept. Agric., Graduate School, Lecture I, Jan. 30, 1928. Quoted from *Conservation of the Soil*, by A. F. Gustafson.

35. Utah, U.S.A. A terraced slope which was previously badly denuded and eroded. See page 163.

communities and industries. Irrigation systems all over the world have been blocked and disorganized by the deposition of silt. Cultivated valley lands in Turkey and Java, for example, have been seriously affected, the cultivation of rice being made difficult or impossible by the deposition of infertile soil carried in the water from the hills above. Other downstream activities, such as harbour development, navigation channels and factories are directly affected by the silt load of the river upon which they are situated. Any appreciable reduction in this silt load must therefore affect a large number of varied interests.

Where valley communities and interests require a great deal of water for human and industrial uses, it may be argued that their supplies might be affected by the over-consumption of water in the upper reaches of a river. Too many dams, especially in a dry climate such as parts of East Africa, may mean too much evaporation, while the transpiration from certain types of vegetation may be excessive. If, however, the plan of water and soil conservation is worked out for an entire drainage system as an entity, the requirements of both upstream and downstream inhabitants and industries can be considered and met by the final scheme of operations. Such a principle has already been adopted in the United States, for the organization of demonstration projects of the Soil Conservation Service and more recently for the Soil Conservation Districts. The organization of most of the projects in distinct catchment areas has made it possible to measure the relative effects of all the conservation practices adopted within the catchment area in terms of the amount of water flowing from different subdivisions of the area as well as the total flowing out of it. This is done by installing water-flow gauges at suitable points.

The cultivation of crops on semi-arid lands introduces special problems of water conservation for the requirements of crop growth and irrigation. Here it is not only a question of preventing excess run-off, but also of conserving the whole precipitation in the most efficacious manner. The disastrous effects of droughts are considerably reduced if all measures are taken to conserve whatever rainfall is available. Even more than in regions with greater humidity, however, the effects of upstream water conservation, storage and use may be seen in a reduction of the

water supply available for downstream activities; new irrigation schemes require large amounts of water, and the evaporation from semi-arid lands is greater than in more humid areas. Conservation schemes in river basins in semi-arid countries must therefore be carried out with a full knowledge of their effects on downstream operations, and conversely, great new irrigation or hydro-electric schemes in the lower valleys should not be planned without a clear knowledge as to what amount of their water supplies represents excessive or erratic run-off from eroding hills and valleys in the upper parts of the watershed.

The main object of practices for conserving rainfall in arid regions is to increase the amount of moisture available for the crop plants rather than to add to the ground water-table with the idea of guiding the water steadily to its outlet as springs or seepage. The system of 'dry-farming' has been developed whereby the rainfall of one year is stored in the soil until the next, when the two years' accumulation will be sufficient for the growth of the crop. This necessitates clean cultivation in the fallow year, in order to prevent weeds from utilizing the accumulating moisture. More recent adaptations of dry land agriculture have been made, and are described in Chapter XIII.

The establishment of forest plantations for protective purposes in arid climates introduces special problems. The technique which has been developed for the particular conditions of the Mediterranean countries has already been described (Chapter XII); the 'gradone' type of forest planting is also being tried in the United States. In the arid western range country contour trenches are constructed in steep grass and scrub lands, with lasting benefits to vegetation and soil; further degeneration of existing depleted stands is immediately stopped, and natural regeneration facilitated. Similar types of trenches have been tested in degraded forest lands in India; although it is claimed that marked regeneration occurs, there is some difference of opinion regarding the value of the method as used in that country, and particularly of the economical aspect of the question.

Grandiose schemes of irrigation of fertile valley lands are frequently put forward as a cure for the agricultural troubles of a country, but, as already noted, the source of the water, its silt-

load, its permanency and the conservation requirements of the upper watershed must also be considered carefully. Whether the irrigation is to be carried on with floodwaters from permanently flowing silt-laden rivers, or with the almost silt-free water supplied from reservoirs which store the wet-weather spates of intermittent streams, any scheme must be part of a complete and well-balanced plan for a drainage basin as an entity. In arid and semi-arid conditions, water collected in contour furrows on pastures and range grassland, in contour trenches in degraded scrub and forest land, or in terraces in arable land, may be stored in small or large reservoirs, for use in irrigation of cultivated lands in the dry season; this may, however, not be feasible in a country with a high evaporation, as for example in semi-arid parts of East Africa, where the rate is of the nature of 1 to 2 cm. ($\frac{1}{2}$ to $\frac{3}{4}$ inch) or more per day during five, six or seven months of the year.

Where the rain which falls on a particular area of semi-arid grassland is not required for storage for irrigation or stock, and where it might do damage in eroding gullies, it may be collected behind a special system of dikes and spread over a large area of level grassland. This method is adopted in the Navajo Reservation in New Mexico, where it is intended to accelerate the regeneration of the overgrazed grassland. This object may be achieved if the silt deposited by the flood water does not choke the grass vegetation.

The whole question of water conservation and use is one of the most complex and involved of the practical problems discussed in this book, and little justice can be done to the subject in one brief chapter. There is so much yet to be learnt. For example, in Africa, practical conclusions cannot be drawn as to the measures which will be of lasting benefit both to the soil and to the people until more is known of the hydrologic cycle, the precipitation, and its more efficacious utilization, and the relation between evaporation, run-off, absorption and transpiration, in different climatic zones, in different soils, and vegetation types; there are vast regions where the actual climate would permit the production of subsistence or even of export crops, but where the unreliable domestic water supply permits the land to maintain only a very small population. The rapid deterioration

of rainfall efficiency now proceeding in East Africa is due to deforestation and soil erosion, and any soil and vegetation conservation measures adopted would automatically improve the water balance. Mr. C. Gillman, Water Consultant to the Tanganyika Government, states that there can be no doubt 'that our [East African] ground-water resources are among our most valuable, if not *the* most valuable asset, that their extent should be accurately mapped, the possibilities of their improvement be carefully studied with the help of the geologist and plant ecologist and every possible precaution be taken, by reforestation and anti-soil-erosion measures, against further deterioration of rainfall efficiency. The destruction of a country's arable soils is bad enough; infinitely worse is the concurrent destruction of its ground-water regime because it is a process faster even than that of soil deterioration and, therefore, liable to put areas that still possess soil out of action because there is no more water for the tillers of the soil.' When the water balance has been restored and a suitable and economic method of storing water for human requirements has been evolved, the situation will be regarded with more equanimity, but that day is far distant, and is rapidly receding with every delay in tackling the problem as a whole.

Finally, we must again emphasize the need for co-operation among all the specialists and practical men concerned, as every bit of work, large or small, that they may plan or carry out must affect all the other dwellers and workers in the same river basin. The work may be quite correctly planned in itself and yet be quite contrary to the requirements of the inhabitants upstream or down the valley; possibly even a slight adjustment in a plan may increase its value many times, to the benefit of all concerned.

CHAPTER XV

Road Construction and Soil Conservation

Departure from equilibrium caused by highway construction. Dangers from 100 per cent run-off from road surfaces. Ditch construction and revegetation of roadside banks. Construction of fast top-gear mountain highways. Improvement of drainage and stabilization of slopes by vegetation.

In countries seriously affected by the erosion problem, the planners and builders of roads must now become conscious of the relation between their operations and the increase of erosion. The departure from equilibrium caused by the construction of a highway through an agricultural countryside of rolling topography or along mountain slopes can rapidly become the direct cause of serious losses of soil and damage to property from the action of drainage water. Practically all the rain-water which falls on a modern highway must leave the road surface in the form of run-off; it is generally concentrated on the roadside ditches, where its volume gives it considerable eroding power. The excess water must be disposed of in some way, and may then cause considerable damage to agricultural or forest land along the highway, by cutting gullies in its passage to the nearest stream or river and by depositing the products of erosion on valuable crop or pasture land.

The road surface itself may suffer, the damage done by water in many parts of the world far exceeding the wear caused by traffic. This is particularly so on dirt or earth roads, where gullying can begin in ruts and later make the road impassable without regrading treatment. In the loess areas of Mississippi, highways have dropped in some cases as much as thirty feet below the surrounding country, and are now flanked by steep banks of erodible material which tends to fall and block the thoroughfare. In such a case the small field streams which pre-

viously flowed safely to the roadside ditch now acquire considerable eroding power through the drop at their outlet, and consequently tend to form gully systems which work back from the highway into the surrounding country.

When the road surface itself is reasonably resistant to the effects of water, the worst damage occurs in the roadside ditches. Where no conservation practices have been adopted, these ditches are generally left raw and unprotected, with steep sides which concentrate all the water in the bottom of the ditch, and with gradients which give the run-off water a considerable and dangerous velocity.

Much can be done by revegetation of roadsides and the construction of broad flat ditches, possibly with simple mechanical structures to give waterways the desired velocity and to protect outlets. It has been suggested that the word 'ditch' should be replaced by 'drainage-way' or 'waterway', these being similar in construction and action to the grassed waterways on terrace outlets.

The establishment of vegetation on steep banks along roadsides is frequently a difficult problem, as the subsoil which is exposed on fresh cuttings and embankments is unproductive or only partially productive, and highly erodible. They are therefore poor sites for plant growth, and much erosion may occur before the protective covering can be established. A special technique is required in connexion with the preparation of the seed-bed, and specially adapted seed mixtures, preferably ot grasses and legumes, are recommended, with the addition of inoculant for the legumes. A nurse crop may be added to give a rapid cover until the other species become established.

Where reserves of good soil are available, the surface of the cutting may be covered with a layer four to six inches deep, upon which the seeds may be sown. Another method is adopted where soil is not available. The seed-bed is prepared by properly sloping the banks, raking the seed-bed (across the slope) and rounding off the intersection of the cut and the undisturbed soil above, to avoid an abrupt slope transition, and so prevent drying out and sloughing off. After seeding and consolidation of the surface, a mulch may be applied, this being of value for several reasons. It retains more soil moisture by preventing

excessive evaporation; it protects the young seedlings from exposure, prevents erosion on the bank and supplies the more important plant nutrients. This mulch should be nutritious, should not blow or wash away, and should cover the ground as uniformly as possible without entirely excluding air and light. A mulch used by the Soil Conservation Service in Ohio was made up of farmyard manure, straw, soil, hydrated lime, superphosphate and ammonium sulphate. Here the work was successful only on properly mulched areas and on slopes of 60 per cent and under.

Mountain highways present their own peculiar problems. The modern motorist demands a fast, top-gear highway which will allow him to travel from one spot to another in the shortest possible time, regardless of the effect his demands may have on the country through which he is passing. The road engineer uses all his resources to produce a super-highway with easy gradients and as few bends as possible. A compromise must be effected by adjusting road alignment to topography, thereby minimizing scenic disturbance and erosion. To do this it is necessary to reconcile the public demand for fast roads with the public sentiment for scenery.

In the construction of new highways, Charles J. Kraebel of the U.S. Forest Service, California, recommends new criteria of location, more rational alignment, greater use of retaining walls and cribbing (a special type of retaining structure, made of the interlacing stems of young trees, etc.), controlled placing of excess material, care in the construction of tunnels and bridges and improved drainage practice—all of which appear necessary if mountain roads are to be not merely traffic arteries, but scenic and conservational assets.

The most important problems in controlling erosion on present mountain roads are the improvement of drainage and the stabilization of the slopes by vegetation. Drainage troubles requiring correction include culverts emptying at wrong points, outfall points not protected against undercutting, too few or improperly placed drainage outlets from the road surface, drainage outlets too small for high-intensity storms, and excess water from minor roads or abandoned stretches of old roads.

It is difficult to establish vegetation on the steep banks of roads

until the slopes have been stabilized by the use of contour wattling, or 'the packing of lengths of brush into continuous thick cables partially buried across a slope at regular contour intervals and supported on the lower side by stakes'. These wattles form miniature terraces, in which the first seeds to be used in the artificial succession from the quick-growing cover-crop of cereals to the final vegetation of shrubs and trees may become established.

The vegetation to be used should be of three types: (1) temporary, consisting of quick-growing cover plants, (2) semi-permanent plants, more effective in anchoring the surface layer of soil, (3) permanent plants, native shrubs and trees which will complete the work of stabilizing the slope with a cover resembling that of the surrounding country.

CHAPTER XVI

The Conservation of Wild-Life Resources

Destruction of flora has led to destruction of fauna. Animal ecologist to assist in establishing a new semi-artificial equilibrium. Wild-life conservation in U.S.A. closely related to soil conservation. Wild life as a supplementary crop for farmers. Rodents and destructive types. Earthworms. Can the rabbit be controlled by disease in Australia? Awakening of interest in wild-life preservation in Africa and India. Influence of animal populations on human beings.

On earlier pages we have made numerous references to the destruction of natural floras and to the great part which the plant ecologist is to play in the revegetation of prairie and forest. It will be obvious, however, that coincident with this destruction of the flora there has occurred a disastrous reduction in the fauna, and that the animal ecologist and population expert is just as important in regeneration work as the plant ecologist. Actually the two must work hand in hand, as many of the botanical changes may be so directed as to be of great advantage to the wild-life population, and conversely, many wild-life introductions may have a great influence on the botanical relationships.

In some cases animals have disappeared as a direct result of the destruction of grassland and forest by overgrazing or fire, or the advance of cultivation and the loss of refuges and food supplies. The innumerable birds, small animals and insects which congregate along streams, in woodland and other waste places are an example. The fish of rivers and streams disappear when the destruction of trees bordering the water, siltation of stream beds and shallowing of the streams expose them to the hot rays of the sun.

In other cases the extinction of a particular type of animal,

bird or fish has been intentional or wanton, being carried out to protect human lives and property or merely for sport. An outstanding example is the colossal destruction of buffalo which took place in the space of a few years in the short-grass plains of the United States late in the nineteenth century.

This is not to say that many of the animals destroyed have not been undesirable, but emphasis must be laid on the fact that a new, semi-artificial equilibrium must be established on the basis of data being collected by the animal ecologist. Many of the animals introduced into any particular environment may not at first glance appear to be essential from a soil-conservation point of view, yet they may fit into a complicated ecological scheme, as one of the links in a food cycle, for example. In any scheme for restocking, all types of animals must be considered, from the apparently useless animals, or the carnivores which keep the numbers of their prey from becoming abnormally high, to the animals which play some important part in the conservation of soil or water, or which may be regarded as an additional source of income to a farmer who has been obliged to retire some part of his land from economic production.

It is in the United States more than in any other country that the conservation of wild life is regarded as an integral part of the whole problem of the conservation of soil, vegetation and water. The organization chiefly concerned with wild-life conservation in the United States is the Bureau of Biological Survey of the U.S. Department of Agriculture. Other Federal agencies adopting a wild-life programme include the Forest Service and the Soil Conservation Service within the Department of Agriculture, and also the War Department. Non-Government bodies concerned include, for example, the More Game Birds in America Foundation, New York City.

The American conservationist directs the reclamation and revegetation of forest, grassland and gullies in the way that will bring the greatest benefit to the wild-life of the particular locality. By making slight changes in revegetating or engineering programmes, conditions may be created which lead to a great increase in the wild-life resources, whether this is valuable from an economic point of view or not. For example, soil conservation workers in arresting certain types of erosion can

achieve the desired end in many instances by utilizing plants, trees and shrubs that are of known food or cover value to wild-life. The forester can combine run-off control with wild-life improvement by mixing patches of food-bearing shrubs and moisture-holding perennial grasses with his pure-stand plantations of commercial species. The restoration of this food-bearing understorey is an important step in the management of forest lands for wild turkeys and deer in the eastern United States. The work of the engineer in conserving water in ponds, reservoirs and other places may also be of inestimable value to many forms of wild life which can find refuge or food in the vegetation of the banks.

The American interest in wild-life conservation has arisen partly because of its relation to soil conservation, partly from a recreational point of view, and partly for the sake of the animals themselves. Under the first head we may group animals like the beaver, which actually assists man in soil conservation and flood control, and also animals, furred, feathered or finned, which can be 'cultivated' on farm woodlots and waste areas as a supplementary 'crop' or food supply for the farmer. Serious stream cutting has often followed the extermination of beavers from certain critical watersheds, while their reintroduction has had most gratifying results. In this connexion, the availability of the principal food trees (aspen, cottonwood and willow) has been determined, as well as the potential number of beavers a stream can support. The low cost and the large amounts of water stored and silt deposited are encouraging factors in this line of work in the United States and Canada.

In addition to the development of an annual self-perpetuating 'crop' of game birds, fur-bearers and game fish to provide supplemental compensation to the farmer for lands retired from agricultural use in the interests of erosion control, the wild-life biologist is also concerned with the encouragement of birds to protect the crops against insect attack and with the welfare of 'creatures that delight the ear with song and the eye with colour'.

Naturally at the same time it is necessary to take steps to control the spread of rodents and other destructive types, although care is necessary before laying the blame on the unfortunate

creatures. The rodents of the range country (gophers, etc.), which have been blamed for the denudation caused by domestic livestock, probably compensate for their supersurface depredations by their subsurface activity in improving soil porosity. There seems to be little or no evidence that rodents or other animals, *under natural conditions* in the United States, promote soil erosion.

Darwin's work with earthworms has a special significance at the present time. According to him, nearly 54,000 earthworms may be found in an acre, and their burrows may penetrate the subsoil to a depth of five or six feet. They must thus have a great influence in increasing the infiltration rate of soils. Possibly the tunnels of ants, termites and other invertebrates of arid regions play a great part in guiding the scanty precipitation into the soil.

There are, however, in many parts of the world animals which are directly responsible for erosion of various types, due to destruction of vegetation. Again opinions vary as to the exact amount of damage done; for example, although individuals may be found who state that the rabbit is so much the Australian pastoralist's greatest problem that modifications of stocking policies would be of little value, other observers such as F. N. Ratcliffe state that it is probable that the rabbit has sometimes been made a scapegoat and blamed for damage and deterioration of which it was not the primary cause. This is particularly the case in the saltbush country in the arid pastoral areas of Southern Australia. In any study of the rabbit as a pest in Australia, it is therefore necessary to obtain exact data as to its effect, as a competitor of the stock, on the carrying capacity of the country, and upon the permanent vegetation. For example, in the case of tree and shrub species, rabbit damage, in the form of destruction of seedlings or stripping of bark, assumes its most serious form, but the presence of stock is just as fatal to seedling mulgas and other palatable species as are the recurring rabbit plagues. Mr. Ratcliffe concludes, however, that even if the scrub country were completely unstocked, the rabbit alone would probably succeed in preventing the regeneration necessary to maintain the perennial plant cover.

Thus the major wild-life problem of Australia is the control or

extermination of the rabbit. The chief hope lies in an epizootic disease, myxomatosis, which shows a maximum spread when a dense and continuous population of rabbits has been established over the land.

The preservation of wild life is also a matter of some concern in other parts of the world, for example, Africa and India. The first International Conference for the Protection of the Fauna and Flora of Africa was held in 1933, and the results of the operation of the convention signed at that Conference were reviewed at the second conference held in India in the spring of 1938. The principles laid down in the convention formed a solid structure upon which wild-life preservation measures should be modelled. The delegates to the second conference represented the Governments of the United Kingdom, the Union of South Africa, Southern Rhodesia, France, Belgium, the Netherlands, Egypt, Anglo-Egyptian Sudan, Portugal and Italy. Each Government reported on the measures taken to provide game reserves and national parks. Although the conservation of soil and vegetation is not such an important part of this programme as it is in the United States, it is obvious that the maintenance of a reasonably natural balance between fauna and flora in Africa is of sufficient importance to warrant our attention.

Similarly an All-Indian Conference for the Preservation of Wild Life was held in Delhi in 1935, when a draft convention was prepared. The Forest Department does everything possible to protect the interests of game and to prohibit the slaughter of game, except under rules of good sportsmanship. The wild life outside forest areas, however, requires protection; much of the destruction is due to the increase in population and in the cultivated land, but much of the emptying of jungles is the result of unregulated and useless killing or trapping carried on without any regard to the interests of wild-life preservation.

In concluding this brief reference to the complex problems of the interrelationship between animals, and of the association of animals and plants, we may quote from the Annual Report for 1936–37 of the Bureau of Animal Population of the University of Oxford.

'There is no human being who is not directly or indirectly influenced by animal populations, although intricate chains of

connexion often obscure the fact. Population problems are as much part of the fabric of daily existence as is the weather. It is quite as interesting to know about changes of population as about changes in the weather, and equally important. What is different is that not only do animals have this influence on man, but man has an increasing power over the fate of the animal populations that still throng the world. There is less of a moral problem about going out on a doubtful day without an umbrella, than there is in ordering the destruction of a species on the chance that it may be doing harm to human interests.'

We cannot condemn the prairie gopher, the Australian rabbit, the African termite, or the locust, without first discovering to what extent, if any, some action of man has upset an equilibrium in animal ecology, and therefore indirectly in plant ecology, and so affected the conservation of vegetation, soil and water.

CHAPTER XVII

Economic Causes and Consequences of Erosion

A soil's capital resources are its fertility. The exchange of financial for soil capital in the modern world. Wastage of soil capital in ancient and modern times. The effect of recent economic events on the spread of erosion in the New World. The turn of the tide. Economic nationalism as a cure. Agricultural adjustment in U.S.A.

Sound businesses are not run by paying dividends out of capital. The purchaser of productive land buys a going concern whose capital is the inherent fertility of the soil. He is courting disaster if he draws continuously on his capital as a way of paying himself a dividend. Soil erosion is the almost inevitable consequence of progressive soil exhaustion, in other words, of drawing upon the capital reserves of fertility.

During the early stages of soil formation, the soil's fertility capital increases, mainly by an increase in its humus content and by the development of a structure which makes the soil a favourable medium for biological activity. The soil's income of potential energy, obtained in the first place from the sun, is greater than its outgoings, namely, the energy expended by plants, animals and micro-organisms living in and on the soil. As the plant community develops, outgoings increase more rapidly than, and ultimately equal, income. A state of equilibrium then obtains and in the absence of any abnormal occurrence little further change takes place in either soil or vegetation.

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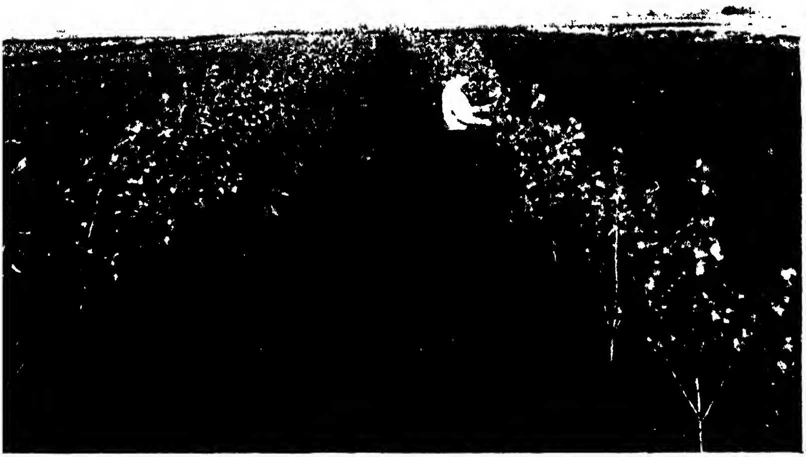
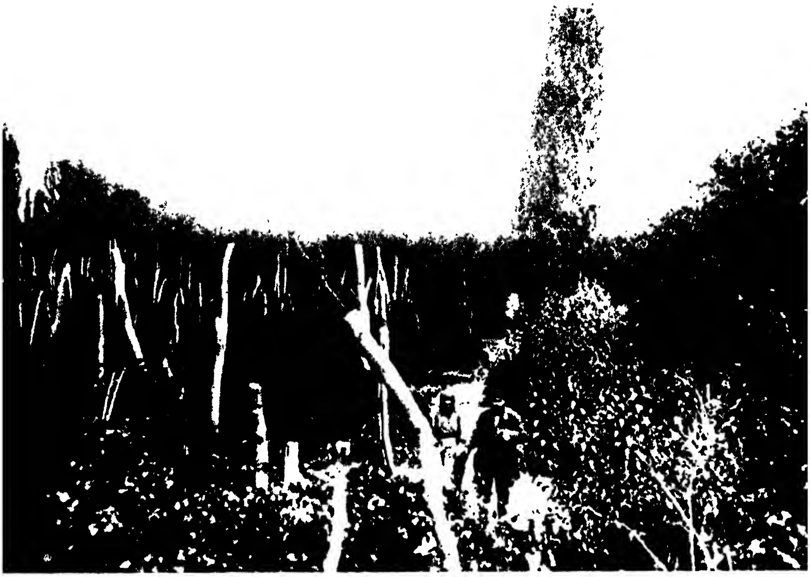
36 *a*. North Dakota, U.S.A. Field shelterbelt. 36 *b*. Washington, U.S.A. Lombardy poplar windbreak; trees approximately twenty years old. See pages 166-169.





A change in the plant régime, from whatever cause, is almost certain to upset this equilibrium. The change may be brought about by a long period of abnormal weather, by a secular change in the climate, by a parasite, fire, man or a host of other causes. A new plant régime will start new soil-forming processes, resulting in either an increase or decrease in the soil's fertility capital when equilibrium is again restored. A decrease is the more commonly observed and is known as soil 'degradation'. When, as a result of slow climatic change, or perhaps owing to the natural ageing of the earth, forest encroaches upon steppe or prairie, the soil is degraded from the rich steppe soil to the poorer forest soil. The human communities that invaded and established themselves on the arid wastes of western Asia likewise degraded the soils. They made the deserts blossom on the solar energy that had been accumulating for ages in the soil, but they paid back little, and in the end the desert returned. Western European peoples have increased the original capital of their former forest soils, and have hitherto avoided soil exhaustion. Their offshoots in other countries are living on capital and degrading the soils with startling rapidity. Under the circumstances they could scarcely have done otherwise, for the New World could not have been developed without the help of foreign capital in the form of money, goods and services, most of which was paid for by exporting soil capital—an apparently harmless procedure at a time when fertility was reckoned in terms of the inexhaustible supplies of plant-food minerals in virgin soils. Physical fertility was but little understood, still less was it realized that physical and biological characteristics were

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37 *a*. U.S.S.R. A vineyard on the Cymljansk-Don sandy lands. The underground water-table is at a depth of two to three metres. In some places the soil has been eroded by wind or buried under sand. A shelterbelt of *Populus pyramidalis* affords protection from the wind. This is regarded as a good example of the possibilities of rational reclamation of vast areas of the Don sandy lands. 37 *b*. U.S.S.R. Plantation of *Pinus sylvestris* on a broken sandy land in Western Kazakstan. In this semi-desert far beyond the southern limit of pine forest this plantation seems to be paradoxical. See page 174.

much more important forms of soil capital, more easily wasted and more difficult to restore, than chemical characteristics.

To see the economic problem of erosion in proper perspective, it is necessary to recognize the part played by huge transfers of financial capital from one country to another and their repayment by drawing on soil capital. Movements of capital have been an outstanding feature of the modern world. They may truly be said to have been one of the mainsprings of progress, but capitalism has never seriously concerned itself with its repercussions on the humus content and structure of soils. Nevertheless, the repercussions have been shattering in their effect and can no longer be ignored.

For our present purposes we can classify eroding countries according to whether the soil degradation that preceded active erosion was mainly the consequence of pristine soil fertility inevitably running down under agriculture, or of the wholesale bartering of soil for financial capital. To the former category belong the old established countries like China, Persia, Mesopotamia and the Mediterranean countries which in their prime were regionally self-contained and were exhausted by the slow wastage that accompanies natural processes of growth and decay. Here the soils' capital reserves had to be tapped from the beginning of agriculture, but the reserves were great, and the demands of civilized communities were nothing like so high as they would be to-day. Under the Mediterranean climate the rapidity of soil formation was sufficient to keep pace for a time with soil exhaustion. Although north-west China is probably more eroded than any other comparable region in the world, it must be remembered that it has taken millenniums to reach its present condition whereas parts of North America have almost reached the same condition within a century.

To the latter category belong those countries where widespread erosion is a recent phenomenon. In many of them the soils are of such a nature that agriculture would have made inroads into their fertility reserves in any case, but had the countries been reliant solely on their own resources, had they not been linked by easy means of communication to other wealthy and aggressive regions, they would have developed slowly, and agriculture, instead of becoming more exploitative,

would have automatically adapted itself to the falling fertility level. The main economic cause of recent accelerated erosion has been the transfer of capital across regional or political boundaries and its repayment with soil fertility. Had Europe solved its population problem by exporting more men and less capital and therefore neither needing nor being in a position to buy so much food from abroad, the world would have been poorer in many ways, but there would have been more soil left for posterity. Progress would have been slow and there might have been no erosion problem to tax man's ingenuity and courage to the utmost and spur him to greater conquests.

Among the newly developed countries, South Africa belongs more to the first than to the second category. Foreign capital has poured into the Union, but has been repaid chiefly in gold, and very little in soil fertility. Gold production has, however, probably had an indirect effect in accelerating erosion by encouraging the farming community to emulate the standard of wealth attained by the mining community. Furthermore, South Africa's mines caused the country to be opened up agriculturally much more rapidly than would have been the case had the only lure to settlement been the very limited opportunities afforded by an arid climate with an uncertain rainfall. Exploitation of the land has attempted to keep pace with exploitation of the mines, and farmers have been encouraged to produce for export, although this policy is likely to be reversed as the harmful effects become increasingly apparent. But the arid soils are of a kind that would have run down under agriculture in any circumstances. The tragedy of South Africa has been the appalling rapidity with which its fertility reserves have been depleted and its thin soil covering washed away. In no other country have the disastrous consequences of erosion followed so quickly after its commencement.

Recent erosion in India and soil deterioration in Egypt must be attributed to the impact of the western type of social organization on other types which had attained equilibrium with the soils on which they had evolved. These two countries support very dense populations, yet they have preserved their fertility through thousands of years by the peoples accepting an economy which precluded a standard of living above what the soils

would afford. As population increased, the standard of living tended to fall, until science and civilization showed how more wealth could be extracted from the soil than was restored by natural processes. Egyptian life centred entirely round the Nile, without whose water and mud there would have been no soil at all. The brilliant achievements in irrigation engineering in ancient Egypt may be contrasted with the primitive agricultural technique which is still practised. The ancient Egyptians learnt how to spread on the land the fertility brought down by the annual Nile floods. They did not exert themselves to extract more than their immediate needs from the bounty of the River. They lived on the soil's income and won lasting security against natural hazards at the expense of progress.

With the introduction of a more efficient technique into Egyptian agriculture, the soils have steadily deteriorated. 'Soil alkali' has become a serious and growing menace, cotton yields are falling. The deterioration has been due in the main to the substitution of perennial for basin irrigation—a substitution which was indispensable for the cotton growing by which Egypt has advanced and enriched itself. Basin irrigation involved an annual five-months fallow (*sharaqi*) during which essential fertility-preserving processes took place; perennial irrigation means forgoing the fallow and taking as much from the soil as it can be made to yield. Egypt's advance from primitiveness to modern civilization is being bought with soil fertility.

In India and tropical Africa, under the benign but not altogether altruistic rule of the European, populations, both human and animal, have increased rapidly; the native inhabitants have received some of the advantages of western civilization, and have often achieved a higher standard of living than they had before the white man came. Money has poured into these countries to release their slender reserves of soil fertility. The eradication of disease, the cessation of internecine feuds, the growth of cities, transport and industry were paid for in soil fertility. Disease and war played essential parts in maintaining the delicate biotic equilibrium of the tropics, eliminating man and beast, tree and plant whenever they became superfluous. Exhaustion and destruction of the soil have produced a superfluity which has been perpetuated by the comparative security

and peace imposed by European rule. The people have been pacified before the elements, and in order to perpetuate peace and provide a 'standard of living' for the people forests have been cleared, pastures have been destroyed, insects and vermin which held the balance between the organic and inorganic forces of Nature have been annihilated. There is no peace in Nature where floods and deserts are spreading through densely populated regions of India and Africa.

The unprecedented economic expansion during the nineteenth century has been followed by a world-wide biological deterioration of the land. The opportunities for expansion and progress were so great that it is very doubtful whether soil exhaustion could have been checked by any means, even had the full seriousness of the consequences been foreseen. By what may or may not have been a coincidence, the need for radically new policies on the land was being realized in the New World at the same time as the Great War was precipitating an economic revolution in the Old World. Coincidentally, the trough of the post-war economic depression was reached during a prolonged and remarkably universal period of drought in the grasslands of America, Africa and Australia. Post-war boom and slump both greatly increased the momentum of the economic erosive forces that were already at work, and drought administered the knock-out blow to millions of acres robbed of their natural defence against climatic vagaries. Probably more soil was lost from the world between 1914 and 1934 than in the whole of previous human history. By 1935 the illusion that nations could get rich quick at the expense of a beneficent, unresisting Nature had been finally shattered.

The boom encouraged the breaking of virgin land and its utmost exploitation while the going was good. With the break in agricultural prices, efforts to extract every ounce of produce from the soil were redoubled, but no money was available for fertilizers or conservative improvements, the need for which became more apparent every year. In widely separated parts of the world the combined effects of boom, slump and drought produced a catastrophic biological and physical deterioration of whole regions, culminating in dust storms and floods which threatened to become fixed events in the calendar of North

America. In May 1934, an estimated 300 million tons of Middle West soil were lifted by one storm and some of it, for the first time in history, reached the Atlantic seaboard in sufficient quantity to darken the cities and choke their dwellers. 'It seemed', writes A. E. Burges,[1] 'as if the very desert had resolved to march on the Capital.' Soil erosion penetrated into the mind and lungs of industrialists, politicians and economists, and assumed the importance of a vital national issue before the American public. The shot fired at Lexington that was heard round the world in 1775 had less influence on subsequent world history than the red dust from Nebraska that settled on Washington in 1934 will have on the future. The echo of the shot passed unheeded over many undeveloped lands and uninterested peoples, but the light reflected from the floating prairie dust has been seen and noticed wherever men pursue their unceasing struggle with the soil.

The depression threw into clear relief an easily comprehensible economic cause of erosion. The farmer was selling his produce below cost and was thereby prevented from taking the necessary measures to maintain or improve soil fertility. Apart from any abstract question of the nature of soil fertility and soil capital, there could be no doubt that financial outgoings were exceeding income. The first step necessary to reverse the position was to raise agricultural prices, by any means, to a level comparable with those obtaining in industry. It does not follow that soil will receive proper treatment when farm income exceeds expenditure, but it will certainly not be cared for when expenditure exceeds income. The numerous measures taken to raise agricultural prices all over the world were not introduced specially to save the soil, but a rise in producers' income was indispensable before soil conservation could be adopted as an integral part of national policy in any country.

High prices, however, do not by themselves encourage soil conservation, but rather the reverse, as the post-war prosperity period forcibly illustrated. He would be an inhuman farmer who did not extract all he could from the soil while a profit was to be made. Conditions favouring soil conservation include not only profitable prices but also an absence of opportunity to utilize

[1] *Soil Erosion Control.* Turner Smith & Co. Atalanta, Ga., 1936.

profits from the land more advantageously than by ploughing them back. Such a combination of circumstances does not occur in an era of expansive industrial progress and prosperity when all the money that can be made out of the land is irresistibly attracted away from it. The foundations of prosperity—soil fertility—have been removed from the exhausted lands, and a superficial material prosperity would now only encourage further and final exhaustion. Man has enriched himself at the expense of the soil; the soil can only recuperate at the expense of man. The economic circumstances of to-day are a natural reaction to what has gone before. They may not be mainly attributable to soil exhaustion, but they are essential for soil recuperation.

If we allow that the present tragic state of the earth's surface is attributable to the economic conditions of the nineteenth and early twentieth centuries, we may assume that erosion will not be generally stopped, much less its ravages repaired, until some economic trend, which will definitely discourage excessive soil exploitation and make the costly reclamation of deteriorated land worth while, becomes manifest throughout the world. Conditions are already changing in a direction leading to the return to newly exploited soils of the capital filched from them during the past century. Economic nationalism, the antithesis of the internationalism which enriched mankind and impoverished the earth, bids fair to save the remaining fruits of internationalism's victory by enabling the obvious, common-sense measures of soil conservation to be adopted on a scale commensurate with the extent of erosion. The medicine is strong and unpalatable, but the Earth cannot safely forgo treatment until the wounds on its surface are healed.

The very fact that practically no conservation policies relative to the land were seriously advocated anywhere before the war indicates the impracticability of introducing conservation under the economic conditions then prevailing. There was plenty of need for conservation; America and Africa had for many years been able to show glaring examples of spreading land destruction; the primary causes of erosion and the measures necessary for its cure had already been realized, but the preventive measures were not acceptable. Everything that the land

could be made to produce could be disposed of, and local restrictions on the means of production were naturally regarded with disfavour. Nationalism, pressing as hard on one's rival as on oneself, has changed all that, and is accomplishing the seemingly impossible task of inducing the human race to put the needs of the land before its own immediate material welfare.

If we consider the principal measures which will have to become basic practices in land utilization if erosion is to be checked and the soil is to recuperate, it will be obvious that they are quite incompatible with a free competitive economy. Reforestation for example, must take out of cultivation areas that could still for several years to come be more profitably used for agriculture. Existing forests must be managed on a sustained-yield system under which the annual cut is restricted to the annual growth increment. Grazing in dry regions must always be limited to the carrying capacity in poor seasons; the natural tendency under a free economy to stock up to the carrying capacity in a good or even 'normal' season has been the bane of American, African and Australian pastures. On pastoral and arable land, in boom and in slump, whether the occupier can afford it or not, capital must be returned to, or at least not removed from, the soil. The economic efficiency of large-scale monoculture and plantation agriculture which form the basis of international trade in food must be superseded by mixed farming, rotational agriculture, 'conservation cropping' and suchlike practices which cost more in money, labour and thought than monocultural systems. The effect on international trade in staple food products if conservative farming were widely substituted for exploitative extensive monoculture would be incalculable, but whatever the effect, it would be more rightly attributed to nationalism than to national efforts at soil conservation.

Conservation systems of land utilization are not necessarily uneconomical; in fact, most, if not all, should ultimately be more productive than are exploitative systems. Some measures whose adoption has been extended by the realization of the dangers of soil exploitation react to the immediate financial advantage of the land occupier, for example, forest fire protection and possibly the so-called 'forestry' system of rubber cultivation in which little or no weeding is done, the natural flora

being allowed to grow and protect the soil by its cover. All conservation farming, however, involves the maintenance or restoration of soil capital and cannot therefore be in general so immediately profitable as exploitative farming where the conversion of soil capital into cash is regarded as a fair dividend on the price paid for the land. The fact that the more capital is restored to the soil the higher and more sustained will be the dividends it will ultimately yield is not to-day sufficient inducement to anybody to put capital back while there is still any to take out. The farming community, impoverished by debt and the wasting away of its principal asset, is in no position to plough its earnings back into the soil. Real earnings from the exhausted Earth have to be supplemented on an immense scale with subsidies, bribes and price manipulations to give occupiers of land all over the world sufficient to keep them going at all.

The necessary inducements to conserve the soil by returning real or artificial profits to it instead of using them for material advancement take the form of onerous restrictions on production and trade which make impossible the free interchange of goods between town and country, and between nation and nation. These restrictions have operated against the material interests of the great majority of people, who dislike them but are helpless to remove them. They are seriously obstructing what appears to be the one ultimate economic goal of mankind—the conversion of all soil fertility into less messy and more easily consumable forms of wealth. In short, they are causing widespread poverty in the midst of potential plenty.

It is scarcely possible to imagine an international conference, called to solve the economic problem of world-wide soil exhaustion, agreeing upon a comprehensive plan—and sixty-odd sovereign governments implementing it—to perpetuate poverty amidst plenty and cause dwellers in towns and distant countries to pay back to the exhausted soils the capital they and their forefathers had taken from them and consumed. Yet Nature's rough justice is achieving that end. The nations are voluntarily denying themselves the inestimable luxury of free international intercourse, made possible for the first time by scientific progress, and the weary soils of the New World will get a chance to rest and slowly recuperate. The Old World no longer welcomes

the surplus produce of the New; it elects to strain its own carefully husbanded soil fertility to the utmost to attain at any cost the goal of self-sufficiency, a dubious refuge in case of war. Economic nationalism is thus slowly but surely effecting a more equal redistribution of soil capital and forcing a check to the excessive exploitation of newly developed lands. Soil exhaustion under the influence of international capitalism during the last century was astonishingly rapid and was accompanied by an all-round increase in material prosperity; soil recuperation promises to be a much more gradual process, unaccompanied by much that the future historian will be able to record as material progress.

The recent wave of extreme nationalism has only swept over the world during the last decade or so, and its healing influence on the soil has scarcely yet had time to become apparent. Nevertheless, it is certain that the warnings of the farsighted would have been unheeded, or not long heeded, had unlimited opportunity for exploitation under a free world economy existed. No nation could husband its resources or curb the application of new science to acquiring wealth under those conditions. Theodore Roosevelt's great conservation plans withered in the expanding prosperity of pre-war America; they died, were buried and forgotten during the war and post-war booms, but they have been resuscitated by nationalism and its parents —slump and the fear of war.

The Agricultural Adjustment Act in the United States illustrate some of the ways in which world-wide nationalism is forcing a country to adopt a conservation policy against the opposition of vested interests and contrary to the national temperament. The refusal of the United States to take payment in goods from their debtors and the high tariffs imposed by, and the poverty of, the debtors caused an enormous drop in agricultural exports in the decade following the war. Acreages and exports of wheat were, approximately:

	Acres	*Exports*
1914	54,000,000	148,000,000 bushels
1920	62,000,000	369,000,000 ,,
1932	57,000,000	41,000,000 ,,
1934	50,000,000	21,000,000 ,,

The acreage required to supply total exports of all crops dropped from 84,000,000 in 1920–21 to 39,000,000 in 1933–34. In view of the situation on international debts, tariffs and foreign lending, the chances of restoring even the pre-war export figures are infinitesimal. The alternative is the adoption of a nationalistic policy aiming at adjusting production to the internal demand. This alternative 'answers the need of the emergency, but demands superhuman efforts if it is to be permanent'.[1] At the same time, the necessary adjustments to a lower level of production in export commodities should give opportunity to rest the exhausted and eroded soils which were unsuitably cropped under the stimulus of war-time prices, and maintained in cultivation under the economic stress of the agricultural depression. The fact that 'superhuman efforts' will be required to ensure adequate rest to the land suggests that nothing short of irresistible external pressure could achieve that end.

The Agricultural Adjustment Act aimed at restricting production to the probable domestic and foreign demand by allotting maximum acreages which each farmer could use for the different crops. Farmers who reduced production were compensated to an extent which made it more profitable to co-operate in the scheme than to maintain their former production without compensation. In this way a very high degree of co-operation was ensured. Compensation was paid from funds obtained from a tax on domestic processing of farm produce. As might be expected, this Act to restrict production and individual freedom (while at the same time grandiose schemes for reclaiming arid lands in other parts of the country were being sanctioned) met with great opposition from all sides, and in 1935 the Supreme Court declared the processing tax to be unconstitutional on the grounds that 'it had been imposed pursuant to an unconstitutional delegation of legislative power'.[2] The necessity of persevering with agricultural adjustment, both as a means of overcoming present economic difficulties and as a long-time policy, is, however, emphasized by the Department of Agriculture which has pointed out that the only apparent alternative is the adoption of a free-trade policy supported by foreign loans to

[1] *U.S. Department of Agriculture Yearbook*, 1934, p. 7.
[2] *U.S. Department of Agriculture Yearbook*, 1936, p. 12.

raise American agricultural exports to their former figure. Incidentally, this alternative, welcomed as it would be by foreign industrial and domestic agricultural interests, would probably extinguish the growing national sentiment in favour of soil conservation.

How far the Act has succeeded in contracting crop acreages and production is difficult to estimate, for since its inception drought has been far more effective in that way than the Act. The Act was conceived as an economic palliative and not as a soil-conserving measure, but its potentialities in the latter direction are now recognized, and the Agricultural Adjustment Administration is coordinating its activities with those of the Soil Conservation Service. The Administration emphasizes the importance of substituting for productive soil-exhausting crops, whose acreage is being restricted, less productive soil-conserving crops like grass and legumes. Every encouragement is given to farmers to practise positive soil conservation wherever they are debarred by human or superhuman forces from soil exploitation. The AAA is a small beginning, inadequate in its results, opposed and partially wrecked by more numerous and powerful interests than supported it, contrary to the canons of orthodox economics, and irritating to American individualism. Within two years, drought largely achieved the AAA's object of eliminating farm surpluses, and apparently removed the need for government interference.

But if drought has been more successful than legislation, it is even less popular and reliable. It removed one economic obstacle to recovery, but it exposed and intensified other more fundamental obstacles to lasting prosperity and security. While the AAA was being condemned as futile, costly and un-American, dust storms were proclaiming that agricultural adjustment must be persevered with and intensified, not for its original purpose of preventing wheat being burnt by not growing it, but in one form or another as the only sure basis of a national soil-conservation policy. The AAA was a shot in the dark, designed to prevent the conversion of soil capital into goods unwanted by a nationalist world; it has come to stay and to develop as an instrument for conserving soil capital whether or not the old opportunities for unlimited exploitation return.

The most dangerous enemy to agricultural adjustment and soil conservation in America would be a revival of economic internationalism, but it is improbable that that will happen before the United States have so re-organized their agriculture under the pressure of nationalism that they have little or nothing to sell abroad.

Sooner or later, far-reaching restrictions on the use of land will have to be enforced in every country where erosion is progressing. Very little direct anti-erosion legislation has been enacted in the world, and where it is in force it is merely a temporary palliative. It dares not strike at the economic cause of erosion. The peoples will not voluntarily forgo the wealth which applied science dangles elusively before them. Without some irresistible economic compulsion from outside, no government could carry through and maintain a policy of moderation amid abundance to be had for the taking. Economic nationalism can apply the screw and make restrictive legislation inevitable, and even beneficent enough to merit the euphemism 'conservation planning'. All over the world it is the fault of the rest of the world that soil conservation has a chance to succeed.

CHAPTER XVIII

Political and Social Consequences of Erosion

I. General Considerations

The maintenance and restoration of fertility on eroding land involve readjustment of conditions of land tenure. The two main problems: adjustment to tropical and semi-arid environments. The plant's supremacy over man on tropical soils. Grassland is intermediate between irrigable land and forest, both of which have been successfully colonized by men. The return of the forest under State protection on deforested land.

The rise in farm prices after 1932 put many occupiers of land into a position in which they could afford to take measures for conserving or improving the soil. Large areas, however, were too exhausted to afford a living at any practical price level, and had to be abandoned. On less exhausted land and in newly settled regions where past mistakes might be repeated in the future, the problem is now to ensure that at least a part of any available profit should be allocated to the maintenance of soil fertility. This world-wide problem must be tackled as a whole, otherwise soil conservers would be placed at an immediate economic disadvantage in relation to soil exploiters. We have seen in the last chapter that the problem is crudely but effectively solving itself through the growth of economic nationalism. It involves also a re-consideration of the conditions of land tenure—a reconstruction of the foundations of national economic systems to conform to the properties of the soils. It has been abundantly shown that the individual equipped with a good market and modern cultivating machinery may become a danger to society if given a free hand with his soil. It has become too easy and too profitable to draw on soil capital, and by overdrawing to postpone the day of reckoning until too late.

To-day, the peoples of the world are groping their several ways towards systems of land tenure compatible with continuing the stability of the soil. Erosion occurs where men hold the land wrongly, whether on forest, grassland or tropical soils, but although the general result is the same everywhere, the conditions of land tenure necessary to ensure soil stability will be found to vary according to the soils and climate. About these conditions, however, the phenomena associated with soil erosion tell us nothing. They merely indicate that something is seriously wrong.

There are several basic sociological problems which the phenomena of soil erosion have brought to the fore in the New World, the most important being the adjustment of a civilized society to a sub-humid or semi-arid grassland environment. Another—the adjustment of civilization to a tropical environment—is much more difficult to solve; indeed, it may be found to be unsolvable without a complete re-definition of civilization. There are numerous intermediate stages between the semi-arid environment (exemplified by the North American prairies) and the tropical environment (exemplified by East Africa). Some of these intermediate stages, notably South Africa, present many of the difficulties of both the extreme stages.

The people of European stock who have occupied the semi-arid grasslands have accommodated themselves with varying success to the physical environment and have assimilated or annihilated the native races. Their task of arresting progressive soil exhaustion is primarily one of adjusting human to natural economy. On the other hand, economic adjustment in the tropics, far-reaching as it must be, pales into insignificance before the problem of racial adjustment. The native inhabitants have enormous physical advantages over their conquerors, and it is doubtful whether the intellectual superiority of the latter goes far to balance the account. The African natives, despite their backward and murderous mode of living (according to modern standards) before the advent of Europeans, had found and accepted their place in an environment where the vegetable world was supreme over the animal world. The Europeans have attempted to rob the forest of its servants, but they have failed to come to terms with the lord. We have paid scant attention to

tropical plant ecology in comparison with what we have paid to more immediately lucrative aspects of tropical life, but unless that deficiency in our knowledge can be made good soon, the tropical vegetation will decide for us the respective parts which white and black men are to play in restoring Nature's equilibrium.

The semi-arid grasslands are usually interposed between arid regions, where agriculture is only possible with irrigation, and temperate-forest regions. To neither of these is civilized man such a complete stranger as he is to prairies and steppes. Civilization was nurtured from its birth on irrigation, and much can be learnt from the past and adapted to present conditions where irrigation communities have to compete with others more favourably placed with regard to water. Soil erosion on irrigated land is seldom so serious a danger as soil alkali, which chemistry and prudence should be able to circumvent without inflicting great economic hardship on the community. Irrigators have always been subject to certain restrictions on the use of their land, if only in connexion with their rights to water. Ancient irrigation civilizations throve on despotism where the State, in the person of the despot, had ultimate control of the use of irrigation water. It may be significant that one of the most successful irrigation communities of recent times—the Mormon colony in Utah—was also founded on a form of despotism.

The disastrous erosion which has followed the destruction of virgin forests in North America and Russia and on important watersheds throughout the world has been the result of opening up forest land too rapidly. Modern civilization should feel most

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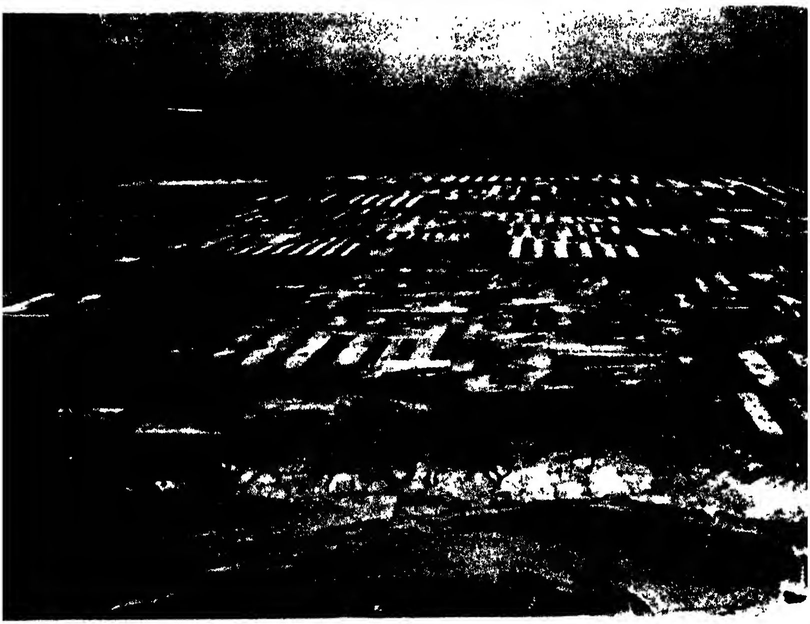
38 *a*. Texas, U.S.A. Photograph taken on June 27, 1936. Uncontrolled erosion has made living impossible, successive wheat failures have occurred since 1932, and the house has been vacated since 1934. No vegetation and thousands of sand drifts over the section, as can be seen in the pasture in the foreground.
38 *b*. Texas, U.S.A. Photograph taken on September 3, 1937. Stabilization of above hummocked field with cover crop. Hummocks levelled in August 1936, drilled to wheat in the autumn of 1936 and blew out. Terraced in February 1937, and planted to a cover crop of milo in July 1937. See page 181.



at home on temperate forest soils, on which it has slowly been evolving for a thousand years. But the evolution of European civilization was a process of gradual and, on the whole, orderly transformation of forest into agricultural land. The opening-up of Eastern America was revolutionary rather than evolutionary. There was insufficient time for natural ecological adjustments to take effect, and men gave little thought to stabilizing the soil with a view to permanent settlement. There was no market for the almost limitless supply of timber, and when the superiority of fire over the axe as an instrument for getting rid of unwanted wood was recognized, the pace of both forest destruction and soil deterioration was enormously accelerated. By the time the harmful effects of fire on the land were recognized, the market for timber had become insatiable, and forests were cut down solely for the sake of their timber, and utterly regardless of the consequences to the soil, which was finished with, as far as the owners were concerned, when the trees had been removed. These heavily cut-over and exploited forest lands are often not only worthless agriculturally, owing to soil deterioration and erosion, but also constitute a serious menace to outlying districts owing to the loss of the control which the former forests exercised over the water régime of rivers. In Eastern America there has been a noticeable tendency within the last few years to allow cultivated and now exhausted former forest land to go into pasture or revert to secondary forest; between 1920 and 1930 there was a decrease of 33 million acres in the cropped area of the United States, mostly in the eastern States. If these abandoned areas are left long enough, they should ultimately become clothed again with good forests.

This modern, rapid conquest of the forest thus promises to be of short duration. The best, and best cared-for, land will remain

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39 *a*. Texas, U.S.A. Photograph taken August 1936. Dunes built up in a field which was native blue-grama pasture in 1930. The land was cultivated for three years only, and then abandoned in 1933. The posts placed around the dune are used to measure the rate of movement. See page 181. 39 *b*. Southern Alberta. Air photograph of strip farming in the first district to adopt this as a community development. See pages 184-5.

under the plough, the exhausted and eroded soils and land occupying key positions on watersheds will be re-forested naturally or artificially. The world demand for forest products increases steadily and will in time overtake the supply; the re-forested land will become a more enduring economic asset than it ever was under agriculture. Nor will the forests ever again be so ruthlessly exploited as in the past. The vital part they play in regulating the waters that can make or destroy a civilized community is now common knowledge gained by painful experience. The forests of the future will be as carefully tended as the most valued arable fields of the past. They will become permanent and protected parts of the State, no longer regarded as mines to be exhausted of their wealth and then abandoned.

The importance of managing forests on a sustained-yield basis has been realized for a long time in Europe where many countries enforce the policy by law—for example, either by restricting forest owners as to the amount of wood that they may cut, or compelling them to re-plant as much land as they clear. While there are indications—they can be regarded as nothing more—that nationalism and the struggle towards self-sufficiency are driving certain European countries, like Germany, to relax in part their traditional protective policies towards their forests, the same influences are facilitating in the more recently exploited forest lands the State enforcement of forest protection.

The tendency for the State to become the principal forest owner is an almost inevitable consequence of adopting or enforcing a protective forest policy, since the benefits are mainly communal. A protected forest usually gives a low return on the capital invested and the capital, while it may appreciate (or depreciate) with time, is unrealizable, besides being subject to risks at least as great as if it were invested in a similarly yielding industrial security. Private forestry on virgin land is notoriously destructive and public opinion all over the world is being mobilized to prevent the harmful exploitation of existing forests. Since protected forests offer little inducement to private capital, resistance to State ownership or control should gradually decline under the combined pressure of public opinion and economic forces.

CHAPTER XIX

Political and Social Consequences
II. The Grassland Environment

The individual's impotence against grass. Collectivism on the Russian steppes. Soil deterioration before and since the socialist revolution. A socialist experiment in soil conservation. The North American Plains. Experts' opinions. The disposal of land by the Federal Government. Private versus *public ownership. The Taylor Grazing Act. Tenancy and soil erosion in Missouri. The relation of land tenure to soil type. The evolution of regional conservation planning in U.S.A. State planning agencies. The Tennessee Valley Project. Soil Conservation Districts. The difficulty of legislating for erosion control. The relation of population pressure to soil exhaustion and erosion. Population and soil productivity in Australia and Canada. Australian aridity and overstocking. Closer settlement and a retreat from the desert.*

The probable future trends of land tenure on sub-humid and semi-arid grassland are still somewhat obscure. Some students hold the opinion that only exceptionally gifted men can hold their own unaided against the unwonted rigours of the grassland environment. The ordinary would-be civilized man destroys, or is first destroyed by, prairie, steppe or veld. This single-handed impotence against Nature is in marked contrast to the strong sense of individualism which the open prairie instils in the settler. Russia has enforced collectivism on a recalcitrant peasantry, not originally as a measure against soil erosion but as an essential part of a revolution that had its roots in the steppes and was nurtured on the disparity between political and natural economy. Erosion in Russia, though widespread and severe, particularly in the highly cultivated black-soil region, was not recognized as a man-made phenomenon until after the

revolution, and its economic and political significance only within the last few years. The advantages of collective farming under State control in the struggle against erosion are now being emphasized.[1]

The position in Russia before the liberation of the serfs (1861) seems to have been comparable to that in America when the possibilities of agricultural mechanization were realized. The landowners' aim was to get the maximum out of the soil in the shortest time with the least expenditure on labour and improvements. Sheet erosion was extensive, though generally unnoticed and not associated with the new gullies that continued to break up the land. Fortunately for Russia, too, the agricultural 'tempo' was much slower than in America. The subsequent growth of a free peasant class, possessing mainly the poorer, sheet-eroded lands and working in direct competition with the large landowners, accelerated erosion further, and as the soils were exhausted or destroyed, cultivation extended on to steep slopes and forest-covered watersheds. The peasants were powerless against the economic and natural forces confronting them, and their influence on the soil was mainly destructive. The abortive agrarian reforms of Stolypin aimed at checking agricultural deterioration by, *inter alia*, enclosing the open-field communes, but were of too short duration to have noticeable results on the soil. Neither did the first agricultural developments after the socialist revolution produce any better effects. The peasants retained individual ownership, the larger holdings being 'liquidated' and the land re-divided on apparently the most equitable basis—namely, in narrow strips running up and down the slopes, and highly conducive to rapid erosion.

Within eighty years the Russian steppes—in what might be regarded as a spontaneous effort to adjust themselves to an awakening civilization—have experimented with and rejected systems of land tenure represented by feudalism, communal open-field farming (1861–1900), enclosures and capitalism (1905–1914), collectivism and socialism (1922). Whether the last-named will evolve into something more enduring and better suited to the steppe environment than earlier systems cannot

[1] *Soil Erosion.* Dokuchaev Institute of Soils: Academy of Sciences, U.S.S.R. 1937. (In Russian.)

yet be foretold. As far as erosion is concerned, there is reason to believe that collectivism of some kind could be made to have a more stabilizing influence on the soil than any previously tried system of land tenure. In particular, it obviates the necessity of taking individual property boundaries and interests into consideration in organizing soil protection on a regional basis. With collectivism and State ownership of all land as fundamentals of agrarian policy, some of the main political obstacles to carrying through a rational soil-conservation programme have been obviated.

With theoretically complete control over the land, the State proposes to introduce a system of crop rotations including several years under sod, with the object of maintaining the natural granular structure of the black steppe soils and developing a similar structure on other soils. This will mean a revolution in natural-grassland agriculture, and we cannot yet say whether it is practicable. On the face of it, mixed farming seems altogether desirable; it would stimulate animal husbandry, provide organic manures, diversify farm produce and bind the farm worker closer to the land, but it must be borne in mind that neither in Russia nor elsewhere has intensive mixed farming been tried out as the standard agricultural system on open, semi-arid grassland. Mixed farming will not necessarily be so well suited to steppe soils with modern technique under socialism as it has been to forest soils under capitalism. Only the future can tell.

The wholesale destruction of Russian and Siberian forests without adequate provision for soil protection is in marked contrast to the well-grounded conservation policy which is being evolved for the plains and steppes. The immense northern primeval forests may receive protection later, but at present their exploitation provides much needed cash which otherwise might have to be obtained at the cost of the fertility of the steppes. It is on these naturally ideal agricultural soils, on which feudalism made little headway and which have escaped the main disaster inflicted by an unrestrained capitalism on the American prairies, that an untried socialism has a clear field for experiment and the greatest chance of success.

Although economic and technical progress has been more

apparent on the North American than on the Russian Plain, economic adjustment to the prevailing soil type has hitherto been less revolutionary. There can be no doubt, however, that adjustment is proceeding apace, and that a main driving force behind the process is the menace of soil erosion. Owing to both climatic and economic circumstances, erosion is more advanced and widespread in the United States than in Canada, but the problem differs in degree rather than in kind on either side of the International Line. American students of the position are fully alive to the terrific impact which erosion is having on the economic structure of the United States. The Report of the National Resources Board (Section I) issued in 1934 commences:

'The traditional American attitude toward land has been to develop and exploit it as rapidly as possible, with little regard for the consequences. This, to be sure, was the natural attitude of a new Nation reacting against the economic restraints of mercantilism and the remnants of medieval land tenure, and confronted with an apparently illimitable array of resources. This attitude contributed to rapid expansion and development, but at the same time produced a planless, crazy-quilt pattern of land use, destroyed or impaired a large proportion of the Nation's irreplaceable resources, and wrecked the hopes, aspirations, and the very lives of untold thousands of people.

'In no other field of our economic activity has the doctrine of *laissez faire* been given freer rein than in the use of our agricultural lands. Farm lands have been used and abused and bought and sold as mere commodities, practically without restriction. Indeed, the extreme of *laissez faire* has been reached with respect to some of the Federal Government's own lands, on which unrestricted grazing has been permitted to the point of destroying valuable range resources.'

The Report of the Land Planning Committee of the National Resources Board 'presents a complete reversal of the attitude of heedless and unplanned land exploitation. It reflects the point of view that public policy should aim at effecting such ownership and use of land as will best subserve general welfare rather than merely private advantage. . . . It points out glaring malad-

justments in present land uses and proposes public policies for correcting such maladjustments and for directing land uses into the most productive channels.'

The conflict between the reluctance of the present generation to renounce the freedom so hardly won by its predecessors and the dawning realization of the inevitable, strikes the keynote of much that has already been done towards effecting a re-adjustment to the natural prairie environment. The United States has not plunged for collectivism as Russia has, but the obvious impotence of the individual to control erosion or even maintain soil fertility in the face of present economic circumstances is driving the nation in that direction. The hope has been expressed, however, 'that through organized, collective action restrictions of inanimate nature may be removed in much larger extent than human restrictions are imposed, and that the net result will be enlargement of opportunity for individual freedom and initiative.'[1]

A warning note that the American people can only preserve their freedom on the Great Plains by submission to a higher authority is struck by another official document.[2]

'The people of the Plains are finding their way toward an attitude of mind, deep-seated and not often brought out into the open, which will affect both their thinking and their doing. Many of the assumptions which the pioneers had found workable in other regions, under other conditions, have proved unworkable on the Plains. The Plainsman cannot assume that whatever is for his immediate good is also good for everybody—only of his long-run good is this true, and in the short run there must often be sacrifices; he cannot assume the right always to do with his own property as he likes—he may ruin another man's property if he does; he cannot assume that the individual action he can take on his own land will be sufficient, even for the conservation and best use of that land. He must realize that he cannot conquer Nature—he must live with her on her own terms, making use of and conserving resources which can no longer be considered inexhaustible.'

[1] *National Resources Board Report*, p. 265.
[2] *The Future of the Great Plains*. House of Representatives Document No. 144. 75th Congress, 1st Session. 1937.

The contemporary transitional period between the old economy suited to the human conquest of North America, and the future economy adapted to securing the fruits of victory by stabilizing what remains of the soil, must be somewhat chaotic, and it is difficult to analyse present trends. The early economy of the western prairies and ranges was a mixture of communism and capitalism, with the former giving way before the latter as the country became settled. The policy of the Federal Government was to dispose of the public domain, cheaply or freely, to States and private individuals and companies with the object of encouraging settlement as widely and rapidly as possible. The attainment of this objective was accompanied by a completely uncoordinated utilization of the land, innumerable malpractices and finally loss of fertility and erosion. The disposal of the public domain did not in general result in stable ownership, but rather in a pernicious kind of shifting, exhaustive cultivation, the owner moving on or abandoning his property after extracting the cream of soil fertility. The average term of farm tenancy in the United States is under two years. The Homestead Acts of 1911 and 1916 flooded the open western ranges with new and often unsuitable settlers and upset the delicate ecological balance hitherto preserved between the mountain summer and the low-lying winter pastures. Cropped land in private ownership expanded in area until 1920; between 1920 and 1929, however, there was a decrease in cropped area of 33 million acres, mostly in the Eastern States where exhausted and eroded soils were allowed to revert to grass or forest. During the same decade there was a slight net increase in agriculture in the Great Plains. In 1934, as a consequence of the growing public concern at the misuse and destruction of the land, the traditional policy of disposing of the public domain was reversed, and the Federal Government began to acquire more land than it disposed of.

A significant indication of the change in national sentiment from unrestricted private tenure to public protection of the land is given by the passage of the Taylor Grazing Act (1934) which 'authorizes the withdrawal from entry of 80 million acres of vacant, unreserved, unappropriated public domain and its organization into grazing districts to be administered by the Department of the Interior. It also authorizes administration of

grazing on land included in withdrawals amounting to about 30 million acres insofar as grazing is consistent with the purposes of the withdrawal. . . . Broad powers are conferred on the Secretary to do any and all things necessary to accomplish the purposes of the law, namely, to regulate occupancy and use of grazing land; to preserve the land and its resources from destruction or unnecessary injury; to provide for the orderly use, improvement, and development of the range; and to continue the study of erosion and flood control and to perform such work as may be necessary amply to protect and rehabilitate the range lands.'[1]

The Taylor Grazing Act may be regarded as a first step towards protecting the soil from the consequences of private exploitation. It will certainly not be the last. There is a growing demand that the 75 million acres classified as 'sub-marginal land' be withdrawn from cultivation by Federal authority and that an unspecified area which may become sub-marginal be fully protected from unrestricted exploitation. Extensive regions have been reserved for public forest, recreation purposes and national parks. How far and in what direction the process of modifying private land tenure will go, is impossible to say, but the alternative to the process is the disappearance of the United States as a world power (within a century, according to some authorities).

Although it is impossible to make any generalized statement that will be true for the whole United States, there has been a widespread tendency—as one would expect—for tenant-worked farms to increase at the expense of owner-worked farms. This tendency has become more marked during the last few years. In one region in the Missouri Valley, for example, tenant-worked farms increased by 35 per cent between 1910 and 1935 and by 8 per cent between 1930 and 1935.[2] A large proportion of the tenants hold their farms on one-year leases, have little interest in maintaining soil fertility, and aim at getting the largest annual cash return from their land, regardless of the future. Similarly, the over-capitalization of land after the war and the increasing

[1] *National Resources Board Report*, p. 204.

[2] *Soil and Water Conservation Experiments.* U.S. Department of Agriculture, Technical Bulletin No. 558, 1937.

burden of mortgage charges incurred as prices fell induced owner farmers, likewise, to farm for the largest cash return, e.g. to put their land into corn, the crop most conducive to erosion under exploitative conditions. Progressive erosion has reduced land values and increases debt burdens and forced sales, thus completing the vicious circle from which escape becomes more difficult every year. A clear connexion has been established between a rapidly shifting tenancy and soil exploitation leading to soil erosion.

A change in the present trend of land tenure in the direction of increasing 'owner-operatorship' or longer tenancies would enormously facilitate the adoption of conservative farming (e.g. beef or dairy farming) which must form the basis of regional erosion control. Apart, however, from other economic complications, such as larger farms, lower labour requirements and cash returns per acre, involved in a change from predominantly corn to grassland farming, the fact remains that tenancy is increasing under pressure of the present economic system. Short-term tenancy, like the erosion which it causes, is but a symptom of the maladjustment between soil and human economics. The same might be said of overgrazing, monoculture, lumbering or any other system of land utilization which leads to soil exhaustion and erosion. The relationship of the occupier to the land will in the end be dictated by the properties of the soil.

This does not imply that the conditions of land tenure must change at every boundary between different soil types, in the way that the natural vegetation changes. The relationship between man and the soil is not so close as that between plant and soil. The human political unit adopts a compromise between the different conditions of land tenure that would be ideal over each type of environment within its boundaries. Until quite recently, no single, highly organized political unit had embraced vast areas of such ecologically divergent environments as humid forest and dry grassland. The relatively small nations of western Europe, singly or collectively, had no problem like this to face, but it is one which must have a determining influence on the future development of political federation in America, Russia, Australia and India. Although we have as yet no experience of a mature and stable civilization existing on

semi-arid grassland, there are definite indications that the requisite conditions of land tenure will be more closely allied to socialism than to the capitalism which achieved such remarkable success on the humid forest soils of Europe, and has been such a disastrous legacy to the prairie soils of America. Perhaps those arch-enemies, socialism and capitalism, will find some compromise which will enable the huge political units of the modern world to retain their present boundaries in spite of internal soil differences.

Although the possibility that soil differences may cause a re-drawing of natural frontiers at some future date cannot be ruled out, it is not at present envisaged. In the United States, however, the idea of *regional* planning, of organizing a natural land unit as a whole and regardless of State or other political boundaries, for purposes of soil conservation is gaining ground rapidly. The need for organizing the conservation of natural resources was recognized over thirty years ago, but the impetus necessary to carry through a national plan was lacking until soil erosion began seriously to threaten the entire fabric of American society. In this respect soil erosion on the American prairies seems to have had a similar effect to that produced by an abortive capitalism on the Russian steppes.

Over forty States now have separate planning agencies which, although often originally set up to relieve unemployment and encourage public works such as town planning, road construction, re-distribution of population, etc., have inevitably concerned themselves largely with land-use planning. In connexion with land-use and soil-conservation planning, however, the lack of correspondence between State and natural regional boundaries, and the sanctity of State rights have often been insuperable obstacles to the adoption of regional conservation schemes. These obstacles are only partly removed by grouping States together in various ways (as has been proposed), since the present, mainly straight-line State boundaries must always be somewhat artificial in relation to natural regional boundaries. Inter-State planning agencies exist in the six New England States and in the Pacific north-west (to develop the Columbia River), but they have as yet no legal status and are primarily liaison agencies between the separate States.

In marked contrast with these and similar agencies, which are attempting regional conservation within the present political frame, is the Tennessee Valley Authority (TVA). The TVA is a body financed by, and responsible to Congress, and its business may be described as the reclamation and stabilization of the badly eroded and destitute natural region formed by the Tennessee River drainage basin. The area of the region comprises parts of seven different States. Several abortive schemes for social and land improvement failed in the past because the sanctity of State rights precluded putting a comprehensive regional scheme into operation. Under the Constitution of the United States irrigation and water-power systems and land-use plans (which enter largely into the TVA's programme) are matters for State legislation. The Constitution offered an insuperable legal barrier to any scheme which necessitated encroaching on State rights over land and water, and faced with the alternative of abrogating sovereign rights or permitting a disaster to be perpetuated on a fraction of their total territories, the States, represented mainly by public-utility interests, naturally chose the latter, as any other States in America or elsewhere would have done.

In order to avert an irreparable disaster to a region equal in area to England and Wales, a way round the Constitution had to be found, and to secure a charter for its work of economic reconstruction the TVA had to express its objects somewhat indirectly. In contrast with land reclamation on State territory, river and flood-control, the benefits from which are not limited by State boundaries, are matters in which the Federal authority can intervene. The TVA was therefore able to obtain a charter to develop the Tennessee River for navigation, but not to stop the erosion which was eating into the vitals of the whole Tennessee Valley. The principal function of the TVA is to maintain a permanent navigable channel nine feet deep in the Tennessee River under all conditions of flow.

The first step towards fulfilling this function was to erect a series of dams in order to control the flow of water at all seasons. The Tennessee River, however, has the typical characteristics of a river draining a badly eroding region. It receives a continuous accession of silt which fills up any artificial channel almost as

soon as it is dug, and its flow is marked by extreme irregularity. The satisfactory maintenance of the navigation channel has consequently necessitated undertaking coordinated flood-control and erosion-control measures throughout the regions, resettlement of a large part of the farming community and complete re-organization of land use. At the same time the dams, under proper land control, will supply a steady flow of water to be converted into cheap electricity which is the TVA's main source of income. With cheap power, industries can be introduced or revived in this derelict region and the foundations laid upon which a stable and prosperous community may arise. Nothing could have been achieved without erosion control which had to be regarded, for political reasons, as an unavoidable by-product of a legally permissible navigation scheme. The TVA has adopted a policy of co-operation with Nature; its worst enemies are not natural forces but the interests that have grown powerful on their exploitation. The desert is beginning to blossom again in the Tennessee Valley. Man and Nature are proving a stronger combination than man and money.

The TVA employs about 13,000 persons, including 4,000 skilled technicians and clerks. Its salary list includes almost every recognized profession and some that would scarcely be recognizable outside the Tennessee Valley. The cost of the projects and improvements destined to be completed by 1943, when the TVA will be ten years old, is estimated at 350–400 million dollars. There is little hope that this outlay will ever be recovered, but against the financial loss must be set the value of the reclaimed land as compared with what it would have been had unchecked erosion been allowed to take its course.

The initial success of the Tennessee Valley project has produced several proposals for similar regional undertakings in other derelict areas, but none have fructified, owing partly to the opposition of political and commercial interests. Less ambitious but more easily realized schemes of regional conservation within States are being put into practice under the provisions of a 'Standard State Soil Conservation Districts Law' drawn up by the Department of Agriculture in 1935 and since adopted by some twenty or thirty separate States. Section 2 of the Act, which defines its constitutional basis and policy, is

worth reproducing if only for the concise statement it contains of the cumulative and far-reaching consequences of erosion.

'It is hereby declared, as a matter of legislative determination—

'A. *The condition.*—That the farm and grazing lands of the State of —— are among the basic assets of the State and that the preservation of these lands is necessary to protect and promote the health, safety, and general welfare of its people; that improper land-use practices have caused and have contributed to, and are now causing and contributing to, a progressively more serious erosion of the farm and grazing lands of this State by wind and water; that the breaking of natural grass, plant and forest cover have interfered with the natural factors of soil stabilization, causing loosening of soil and exhaustion of humus, and developing a soil condition that favours erosion; that the topsoil is being blown and washed out of fields and pastures; that there has been an accelerated washing of sloping fields; that these processes of erosion by wind and water speed up with removal of absorptive topsoil, causing exposure of less absorptive and less protective but more erosive subsoil; that failure by any land occupier to conserve the soil and control erosion upon his lands causes a washing and blowing of soil and water from his lands on to other lands and makes the conservation of soil and control of erosion on such other lands difficult or impossible.

'B. *The consequences.*—That the consequences of such soil erosion in the form of soil-blowing and soil-washing are the silting and sedimentation of stream channels, reservoirs, dams, ditches, and harbours; the loss of fertile soil material in dust storms; the piling up of soil on lower slopes, and its deposit over alluvial plains; the reduction in productivity or outright ruin of rich bottom lands by overwash of poor subsoil material, sand, and gravel swept out of the hills; deterioration of soil and its fertility, deterioration of crops grown thereon, and declining acre yields despite development of scientific processes for increasing such yields; loss of soil and water which causes destruction of food and cover for wild life; a blowing and washing of soil into streams which silts over spawning beds, and destroys water plants, diminishing the food supply of fish; a diminishing of the underground water reserve, which causes water shortages,

intensifies periods of drought, and causes crop failures; an increase in the speed and volume of rainfall run-off, causing severe and increasing floods, which bring suffering, disease, and death; impoverishment of families attempting to farm eroding and eroded lands; damage to roads, highways, railways, farm buildings, and other property from floods and from dust storms; and losses in navigation, hydro-electric power, municipal water supply, irrigation developments, farming, and grazing.

'C. *The appropriate corrective methods.*—That to conserve soil resources and control and prevent soil erosion, it is necessary that land-use practices contributing to soil wastage and soil erosion be discouraged and discontinued, and appropriate soil-conserving land-use practices be adopted and carried out; that among the procedures necessary for widespread adoption, are the carrying on of engineering operations such as the construction of terraces, terrace outlets, check-dams, dikes, ponds, ditches, and the like; the utilization of strip cropping, lister furrowing, contour cultivation, and contour furrowing; land irrigation; seeding and planting of waste, sloping, abandoned or eroded lands to water-conserving and erosion-preventing plants, trees, and grasses; forestation and reforestation; rotation of crops; soil stabilization with trees, grasses, legumes, and other thick-growing, soil-holding crops; retardation of run-off by increasing absorption of rainfall; and retirement from cultivation of steep, highly erosive areas and areas now badly gullied or otherwise eroded.

'D. *Declaration of policy.*—It is hereby declared to be the policy of the legislature to provide for the conservation of the soil and soil resources of this State, and for the control and prevention of soil erosion, and thereby to preserve natural resources, control floods, prevent impairment of dams and reservoirs, assist in maintaining the navigability of rivers and harbors, preserve wildlife, protect the tax base, protect public lands, and protect and promote the health, safety, and welfare of the people of this State.'

The object of the Act is to provide for the organization of soil-conservation districts with power to administer erosion-control schemes and to enforce desirable land-use regulations.

Little active opposition to the Act has been encountered; that it has not been adopted by all States is due principally to indifference, caution or minor objections to some of the clauses which may be altered by individual States to suit special circumstances.

When a State has adopted the Act, a soil conservation committee is set up to assist in establishing 'soil conservation districts' and to coordinate the programmes of the different districts. To form a district, any twenty-five land occupiers (tenants or owners) may petition the committee, which then proceeds to take a vote among all occupiers of the proposed district. Action can only be taken on a majority vote. When this has been obtained, five supervisors are elected, three by the land occupiers and two by the committee. The supervisors are authorized to draw up a land-use programme for the whole district which becomes binding (but may be modified) after it has been approved by a majority of land occupiers. The programme, for instance, may reserve certain areas for forest or pasture, may insist on terracing here and strip-cropping or rotational farming there. When once the regulations have been laid down, any farmer infringing them is liable to severe penalties. The occupiers retain all their legal title to their land, but in the use they make of it the interests of the community take predecence over those of the occupier. The district, in fact, becomes a modern form of the medieval open-field commune. A fully organized soil-conservation district will have a pattern as distinctive as, though naturally very different from, that of the medieval manor. Moreover, it will acquire a certain amount of autonomy and tend to become a political unit, with boundaries fixed by geography and possibly having more significance than the present county or State boundaries. Each district is independent of the State committee, whose duty is to coordinate the work of the several districts within the State.

The work undertaken by the districts may be financed in several ways: (1) the landowner and land-operator who benefit

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40 *a*. California, U.S.A. Gully formed in the flood of March 2, 1938. See page 56. 40 *b*. Pennsylvania, U.S.A. Wreckage of bridge subsequent to the floods in the spring of 1936.

directly from the application of erosion-control measures to their lands may bear a share of the expense, furnishing labour, materials, equipment, etc.; (2) the State and Federal Governments may also bear a share. Appropriations may be made available out of funds in the State treasury and allocated by the State soil conservation committee, and services, funds, and properties may be contributed by the United States through the Department of Agriculture or other agencies.

There is every prospect that soil conservation districts will become a common and characteristic feature of land tenure on the eroded soils which cover the greater part of the United States. It depends on whether they succeed in their prime object of permanently checking erosion and restoring soil fertility. It is significant, however, that the conception of soil conservation districts involves an apparent reversal of the Nation's 'reaction against the remnants of medieval land tenure'. It suggests that men are once more becoming ready to submit to the dictates of a still unconquered Nature and, if necessary, to force submission from their recalcitrant or too self-seeking fellows. In some form or other, community farming, regulated so as to enrich the soil before the individual land occupier, has figured prominently in the early stages of all successful civilizations. There seems no reason to assume that that stage can be dispensed with under the trying conditions to which modern agricultural technique subjects virgin land.

Emphasis is laid on the democratic basis of soil-conservation

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41 *a* and *b*. Minnesota, U.S.A. Lake Como has been a famous resort for the past seventy-five years. The lake was built in 1861 to furnish waterpower for railroad shops and a flour mill. In 1909 heavy rains and floods washed out the earth dam, leaving a dry bed from 1909 to 1922, when a new dam was built and the lake reformed. Silting became more rapid between 1926 (upper picture) and 1936 (lower picture) because farmers up-river cut the timber, cultivated more of the hill-slopes and left little vegetation to retard run-off. At times the silt was so thick in the lake that most of the fish and other marine life were killed. On occasions wagon-loads of dead fish had to be taken out after a heavy rain. See page 193.

districts. Land-use regulations are devised, approved and operated only by a majority vote of land occupiers. This democratic basis undoubtedly facilitated the adoption of the Standard Act by twenty-two States[1] during 1937, and nipped a good deal of possible opposition in the bud. It is the hope of the Administration that soil-conservation district laws will ultimately be passed by most, if not all, of the States, in which case the 'district' should become an established feature of the national social organization. The Federal Soil Conservation Service is strongly advocating the principle of co-operation among large groups of farmers organized under State law, and now establishes new demonstration projects only in States with adequate soil-conservation laws. This rule has been adopted because the value of demonstration projects is enormously increased where a large measure of co-operation from farmers is assured.

Only in the United States has popular opinion been stirred sufficiently by the ravages of erosion for the people to take the initial steps to put their house in order. It cannot be too strongly emphasized that the stabilization of eroding lands—re-adjustment to the environment—cannot be effected by purely dictatorial legislation. There is probably only one way of establishing a stable human community in harmony with the soil and climate of any particular region, and legislators are not particularly favourably placed to know what it is. The difficulties encountered in formulating practical legislation, and the opposition encountered by proposed laws for regulating land use, are significant. The Standard State Soil Conservation District Law is an extremely flexible instrument and in its flexibility lies its best hope of success. It may fail—as the less flexible Agricultural Adjustment Act failed, and reappeared in a form modified by experience. At present, all that can be said is that the Soil Conservation District Laws and the Agricultural Adjustment Acts indicate evolutionary trends in the matter of national soil conservation. In other countries these trends are less apparent. The

[1] Arkansas, Colorado, Florida, Georgia, Illinois, Indiana, Kansas, Maryland, Michigan, Minnesota, Nebraska, Nevada, New Jersey, New Mexico, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Carolina, South Dakota, Utah, Wisconsin. Montana adopted an 'unsatisfactory' statute, and the Governors of Texas and Ohio vetoed statutes passed by the State legislatures.

people may be as alive as the Americans are to the dangers that beset them, but they have not progressed so far towards seeking a way out.

It is unlikely that any effective and lasting organization to protect the soil from misuse and erosion will evolve in a country where the pressure of population on the land is small or non-existent. Australia and Canada afford instances of such countries, where erosion has nevertheless been extensive and is increasing rapidly. Population-density figures are apt to be misleading, particularly as both Australia and Canada have huge uninhabited and uninhabitable regions, nevertheless it is worth noting that they contain about two people per square mile as compared with about thirty in the United States. With modern facilities for exploiting the soil, ample land and to spare for everybody is more likely to lead to soil exhaustion than land hunger, since the ease with which fresh land can be obtained militates against the practice of conservative husbandry. For this reason we hear little about the menace of soil exhaustion in Argentina and Brazil, although there is no doubt as to its widespread occurrence, particularly on Brazilian coffee plantations. When good land is abundant, soil erosion—as distinct from soil exhaustion—does not occur to any great extent, since exhausted land is abandoned before noticeable erosion sets in. Only when the population begins to press on to already exhausted land does erosion—the consequence of soil exhaustion—become sufficiently serious to compel the nation to organize countervailing measures. Until population pressure reaches a certain intensity the disease spreads insidiously and untended.

The necessary pressure will ultimately be obtained either by increases in population, or by decreases in the area of productive land, assuming that the population remains stationary. At present the maximum productive areas, or at least productivities, of Australia and Canada are tending to contract more noticeably than their populations expand. Naturally it is to be hoped that in future the stimulus to undertake the process of radical readjustment, which accelerating erosion shows to be inevitable, will come from the pressure of expanding populations on the land, and not of expanding deserts on the people, but both countries appear to have a long way to go yet before

the stimulus becomes powerful enough to be translated into action.

Mention of the desiccation of the Canadian West almost invariably produces a counterblast of protest that there is ample good land for all and that the pioneering spirit still lives in the people strong enough to overcome all difficulties. Such protests will not be without avail if they induce new pioneers to strengthen the battle front against the drifting soil. The Dominion and Provincial Agricultural Departments are aware of the creeping threat to the prairies' future. Under the Prairie Farm Rehabilitation Act (1935) provision is made for an amount not exceeding $1,000,000 a year to remedy the consequences of recent droughts and soil drifting. The money is used for research, education, propaganda and direct assistance to farmers who are prepared to carry through a soil-conservation programme laid down by their District Experiment Station. Circumstances, however, are not favourable to that active co-operation among all farmers in a district which to an increasing extent characterizes the American attitude to the land. The question has been asked how long the Prairie Provinces (notably Saskatchewan) can remain predominantly wheat producers, but no practicable alternative to an agricultural system that has already become a tradition has been proposed. From the standpoint of soil resistance to erosion, the Canadian prairies are climatically somewhat more favourably situated than the American, and as experience and knowledge of how to manage prairie land accumulates, Canadian agriculture may develop without any violent change towards a state of equilibrium with the soil. On the other hand, there is little social or psychological inducement to imbue the prairie farmer with a friendly spirit of co-operation with the hard landscape that surrounds him, and the West may have to proceed a good way farther along the road to disaster before a halt to soil deterioration is called.

A similar state of affairs prevails in Australia, where the chief enemy is wind erosion on semi-arid pastoral land and on the wheat fields of the South Australian 'Mallee'. There is, however, less virgin but habitable land available for overflow as the present settled areas become exhausted than in Canada, and the settled semi-arid areas, thinly populated as they are and always

must be, are eroding much more severely. Mr. E. S. Clayton, an experienced and travelled observer, has stated his opinion that erosion in Australia, though not so advanced as in the United States (owing to the shorter period of exploitation), is proceeding at least as rapidly, perhaps more so. To speak of population pressure on a country of three million square miles and containing six million people, three quarters of whom reside in the south-eastern corner watered by the Murray River, may sound fantastic even when allowance is made for the large area of true desert. Except for the north-eastern corner and a part of the tropical north, however, practically the whole continent suffers from a real lack of water, both as regards rainfall and rivers which might have been used for irrigation. Probably not more than one-fifth of Australia is cultivable land.[1]

The impossibility of increasing the supply of this essential raw material, water, by any known or imaginable means sets a low upper limit to the population Australia can support. Equally it limits the total productivity of the land; it is as useless to feed a thirsty soil as to feed a thirsty man, as the food only increases the thirst. The use of high-yielding crop varieties is also barred to a large extent, since high yields require a proportionate amount of water for their make-up. Science can help chiefly by discovering drought-resistant plants and cultural methods that will reduce evaporation from the soil to a minimum and increase water absorption. Wild animal populations are likewise limited by the amount of vegetation procurable, and increase or decrease from year to year within a given region according to the rainfall. Domesticated livestock numbers, however, are not so rapidly adjustable to the weather. A farmer stocks his land with, say, a hundred sheep to the square mile on the basis of a normal year's rainfall and cannot readily reduce the number to ten the next year if the rain does not come. Instead, he overgrazes his pastures in an effort to keep as much of his stock as he can, erosion sets in and the safe carrying capacity of the land is permanently reduced. He becomes involved in the usual vicious cycle of erosion. As the safe carrying capacity is frequently very much lower than the commonly accepted level for normal years, there

[1] C. B. Fawcett, 'The Extent of the Cultivable Land,' *Geographical Journal* vol. 76, 1930, pp. 504–509.

is an almost irresistible tendency to overstock, particularly if one's neighbour is more favourably situated or is himself overstocking. Moreover, in Australia as elsewhere, many of the financially less sound stations fell into the hands of the Banks during the depression and were unable to pay interest and amortization while prices were low. They are now being called upon to bear heavy annual charges which practically necessitate overstocking.

The immensity of individual properties and the very low population density (one per 10 square miles, say) in the semi-arid pastoral regions place great difficulties in the way of co-operation or coercion to ensure that the safe stocking level is not exceeded. This is the main human problem that must be solved before progressive land wastage can be checked. The introduction of drought-resistant pasture plants, the destruction of rabbits and other pests, the control of weeds like the prickly pear which has taken possession of millions of acres will be of little value to Australia unless overstocking can be generally prevented. Apart from the difficulties of enforcing restrictive legislation Australians appear to be averse to the idea, preferring to wait until the position has been clarified by investigation and research. It is improbable that the handful of men available and working independently for their own immediate salvation will be able to stem the desert tide. Encouragement of closer settlement in the more favoured regions is now the policy of most of the States and together with natural trends may lead to a general strategic retreat before the desert until such time as opportunity and accumulated experience permit a counter attack to be made. The spread of the desert will itself tend to produce closer settlement elsewhere, and without closer settlement, more intensive and therefore better farming and greater opportunities for co-operation than exist at present, there is little likelihood of securing coordinated and effective action against wind erosion.

CHAPTER XX

Political and Social Consequences
III. Tropical Africa

European responsibility for erosion. The fallacy of tropical soil fertility. Erosion from European and native standpoints. Shifting cultivation. Tropical produce is largely unaffected by economic nationalism. The supremacy of tropical vegetation over man. The need for ecological research. The human-ecological aspect of erosion. Co-operative soil conservation is essential. Unnatural boundaries between European and native areas. Land tenure. The tribal system. Individual land tenure. The African's attitude to the land is the main stumbling block to applying straightforward soil conservation. Examples of successful native soil conservation. Binding the cultivator to the soil. Advantages of feudalism. The soil requires a dominant. Ecological analogies.

Responsible authorities agree that soil erosion in Africa to-day offers an almost insuperable obstacle to future progress in the direction which enlightened opinion had planned for the continent. From Cape Town to Cairo, European influence has been responsible for the rapid, and in places now uncontrollable, biological deterioration of the land. Whatever European plans for the future of Africa may have been, whether their object was imperial, commercial, educational, religious or military, they included no provision for the safety of the soil. At the time when Africa was being colonized there was no apparent reason and little precedent for caution. The luxuriant tropical vegetation suggested immense wealth to be had for the taking; it seemed only necessary to introduce scientific technique and to substitute a settled agriculture for the inefficient shifting cultivation of the natives. But the soil has yielded up its wealth too readily, and its apparently boundless fertility dis-

appeared under European agricultural methods before the damage being done was realized.

The Europeans, however, are now fully alive to the impending disaster. They know what measures should be taken to ward it off, they have begun to adopt those measures and they are prepared to make considerable sacrifices to ensure their success. They are learning to recognize the limits within which a moist or semi-arid tropical soil can be exploited and they are altering their lives and agriculture accordingly. Were it not for the natives, erosion control might perhaps be left to European common sense and ingenuity. Nature destroys quickly in the tropics, but given the chance she restores equally quickly.

The natives, often segregated in overcrowded reserves and practising a mixture of traditional and modern agriculture on indifferent land, are in general more active agents in erosion than the Europeans. Many tribes are by tradition nomadic pastoralists, and what agriculture they have learnt under European rule and instruction has been mainly exploitative. The natives have not yet learnt to see in erosion an imminent danger threatening their whole existence. Their nature revolts against denying themselves what is left of the present for the sake of a problematic future. They still retain age-old customs which had their place in the former balanced scheme of Nature but are destructive under civilized conditions, and they have adopted others which have no relation to the natural environment. They are often afflicted with land hunger which militates against any gradual re-adjustment to the changed circumstances under which they must live. Were it not for the Europeans, however, the natives also could put a stop to soil erosion. War and disease, nomadism and shifting cultivation would soon give Nature the short respite she requires in which to recuperate. With a little more education and contact with the white man, the native may lose the attributes that would enable him unaided to preserve his country from destruction.

The position may be described somewhat differently. Only exceptionally is the white man or the black man the dominant species in a tropical environment. The black man has seldom even simulated dominance. The typical basis of African society has been shifting cultivation or nomadism; man occupied the

land for, say, five years, the vegetation for forty years during which practically every trace of human influence both on the vegetation and the soil was erased. Shifting cultivation, with all its drawbacks and inefficiency, was the only system under which races backward by modern standards could safely cultivate the tropical forest, and nomadism the only system under which the grassland could be safely pastured. To-day, shifting cultivation, the sign of man's subordination to the vegetation, has become a principal cause of soil exhaustion and erosion in Africa, due to the shortening of the soil's resting period necessitated by increasing populations and the general tendency towards a more settled mode of life since European occupation.

It is difficult to imagine Europeans permanently submitting to a position subordinate to the vegetation in African economy, that is, to a position little above that of the wild beasts. Indeed, having to a certain extent tamed the native races, their only justification for remaining in Africa is to tame the vegetation. The white man's burden in the future will be to come to terms with the soil and plant world, and for many reasons it promises to be a heavier burden than coming to terms with the natives. Apart from inherent constitutional disadvantages, the white man began badly by ignoring the reactions of the soil, with the result that he has now to deal with a deteriorated biological environment directly imperilling his existence. Again, no external pressure has borne on tropical colonies to encourage them to adopt conservative farming, and the entire temperately situated world is crying out for tropical produce which it cannot itself produce. It protects its beet sugar against the much more cheaply produced cane sugar of the tropics, but tropical cotton, rubber, tea, coffee, fruits, etc., have few competitors in nationalistic Europe. Sugar cane scarcely enters into tropical African economy; cotton and coffee, on the other hand, have recently expanded enormously and constitute two of the principal cash crops of both European and native farmers, besides being crops whose cultivation readily induces erosion. A natural stimulus, moreover, exists to produce crops for export rather than for local consumption, since only exports can purchase the amenities of civilization. But the skin-deep fertility of the tropics is also exported with the produce of the soil.

The subordinate position which the native human population has occupied in tropical African economy in comparison with that held by the vegetation is not always fully appreciated. The people and the politicians in the metropolitan countries still act as though the natives rather than the native plants were the most serious rivals to their colonial dominions. Therein, in fact, lies a source of growing conflict between metropolitan and local authorities. The retention of tropical colonies is nowadays mainly justified on the excuse of a civilizing mission to the natives; and the view that the natives must be treated as secondary pieces in the coming battle between the dominants of the temperate and tropical regions is politically untenable. The political obstacles to executing a bold erosion policy in tropical Africa are immense and explain the apparent reluctance of colonial administrations to move in the matter as quickly and decisively as the circumstances demand.

Since erosion proceeds much more rapidly and is more destructive in tropical than in temperate regions, the need for prompt action is obvious. Some authorities, basing their argument on the fact that the consequences of erosion accumulate at a high rate of compound interest, assert that 'the Great African Desert, uninhabitable by man' will become a reality in a very few years unless drastic anti-erosion measures and legislation are enforced immediately. The outcome of the battle of the dominants is by no means a foregone conclusion. The white man has partially subdued his human rival in the tropics, he is beginning to tackle seriously the matter of soil control, particularly from the engineering standpoint, but plant ecology in its relation to the position the white man proposes to occupy in Africa has scarcely been touched upon. Experience in cooler regions has taught men that if they can control the soil they can control the vegetation and adapt it to their own needs. In cool regions we can completely change the natural soil type, and thereby the natural vegetation too, by physical and chemical means; in the humid tropics we can only effect radical changes in the soil by controlling the vegetation, and at present we have little lasting control. It seems as though mastery over tropical soils must be secured with the help of the ecologist rather than of the engineer or chemist, and in the world at large the eco-

logist does not command the same respect as either of the others. But the crying need in the tropics, if white civilization is to retain even its present parlous hold, is for more biological science, and for plant biology even more than for medicine, entomology or anthropology. In view of the much greater returns offered by research in physical sciences all over the world, what chance has tropical plant ecology of receiving the support it should have—on a scale, for example, comparable with that given to applied chemistry? The principle stimulus to ecological research will come from the cumulative destructiveness of soil erosion which is becoming a graver and more intractable question than disease, pests and inter-racial antagonisms, and the focal point at which all these other problems meet.

We recognize the dangers in making any broad generalizations about so diverse a region as tropical Africa, but in a brief survey such as this we must either look at the wood and ignore the constituent trees or look at a few selected trees and ignore the nature of the wood. We propose to confine attention to the wood. We shall try to show the present trends in the process of ecological re-adjustment necessitated by the impact of European civilization on a tropical environment. In the tropics destruction of the land is so rapid, when equilibrium is destroyed, that there is no time for the more leisurely adjustments by trial and error which have characterized the evolution of civilization in temperate countries. Present trends, therefore, are likely to have a greater significance in the tropics than elsewhere. Within a few years' time there will be no turning back from the path we shall have taken.

As is well known, the basis of African agriculture was shifting cultivation, as it was also the basis of prehistoric European agriculture. Had contact with white civilization not been made, it is reasonable to assume that the development of native races towards the state of 'divine discontent' by which General Smuts characterizes modern civilization would have been a gradual process taking centuries or millenniums. Agriculture would probably have changed imperceptibly towards a more settled system as the cumulative influence of generations of men on the soil favoured such a change. For every time a plot is cultivated some slight change is made in the individuality of the soil, and

when the plot is abandoned the returning vegetation is not quite the same as before. After the next cultivation, perhaps fifty years later, man's impress on the soil would become stronger and so the process might go on without any radical disturbance of the natural equilibrium until men became the dominant influence on a changed soil adapted to settled agriculture. Such an orderly sequence of events might have taken place in Africa—or it might not. It undoubtedly took place in Europe, and possibly in tropical Central America where, however, the resulting Mayan civilization was but a passing phase in the soil's evolution.

Had the natives thus gradually secured control over the soil, they might then have had opportunity to develop their own 'civilization' on a firm and natural foundation of experience won from Nature. Such a seemingly idyllic state of affairs, however, is not to be unless we assume that white domination is a transitory episode in African history during which the spark of divine discontent has been fired.

The introduction of European agriculture and the adoption of semi-continuous cultivation by shortening the land's resting period meant in effect that mankind, white and black, had assumed dominance on soils that were still by their nature suited only for the indigenous vegetation. Human dominance has its allotted period in the biological succession of a region, and we do not know enough about ecology, nor have we sufficient power to change the soil at will, to be able to skip the intermediate, natural stages between dominance by forest or savanna and dominance by man. Neither do we yet know what the intermediate stages should be, but the probability is that we must go back to the beginning and learn. What we have to learn is not only the appropriate agricultural systems and operations but also what type of society—tribal, feudal, despotic, democratic or otherwise—can co-exist on the soil during its transition from a plant-dominated to a man-dominated type. It is unlikely that any advanced type of social organization can be built up until men have complete control over the soils and plants, and it will be mere chance if the type that does evolve conforms with the aspirations of enlightened opinion.

It is still too early to see clearly the trend of social evolution among white communities in tropical Africa, but soil erosion

which is virulent in Kenya Colony and Southern Rhodesia has already led to a considerable degree of co-operation among private and public landholders for their mutual protection. A further extension of co-operation against erosion in European reserves along the lines adopted in America could have been anticipated, had the matter not been complicated by conflicting racial interests and the contiguity of native reserves in which, largely as a consequence of decreasing soil fertility, pressure on the land tends to become excessive. The European community is thus faced with the necessity of presenting a united front both against erosion and the almost irresistible pressure of the land-hungry native population. The prevention of further erosion on native land is at least as vital to European security as on alienated land, apart altogether from humanitarian principles.

According to the principle of segregation, which is proposed as one means of solving or obviating racial problems, it is urged that native and European agriculture should each develop along distinct lines. Indeed, it is difficult to imagine that segregation would endure were the agricultural bases of native and European society to develop along the same lines, or that European agriculture organized primarily for export could compete economically with a similarly organized native agriculture. The idea that natives should be encouraged to produce export crops in order to raise their standard of living is being abandoned, both for the sake of the soil and in the economic interests of the European. The wisdom of developing native agriculture along natural lines as far as that is possible within the framework of European civilization can hardly be doubted, but it is questionable whether a collateral development of a distinct European agriculture along the lines desired by Europeans is at the same time feasible. Here again, erosion control promises to be the decisive factor in the long run.

It is necessary to bear in mind the extreme sensitiveness of the soil-plant organism in the tropics. The organism is easily and seriously disturbed by even slight deviations from the appropriate methods of land utilization—e.g. by shortening the resting period of shifting cultivation. It is less feasible in the tropics than in temperate regions to restore a disturbed equilibrium on the land by patching up one area independently of other, topo-

graphically associated areas. Patchwork erosion control is still the order of the day and where applied has often achieved considerable success, but it is freely admitted that such control is at best a temporary palliative until suitable organizations are evolved for tackling actual and threatened erosion on a regional basis. Only by the unified treatment of complete natural regions can permanent stability be secured. Appreciation of this fact is reflected in the increasing co-operation among European landholders and public-works departments. Natives also are being taught or compelled to co-operate to save their reserves.

Since, however, native reserves have usually been demarcated not primarily on a regional basis but rather with the purpose of alienating the land most suitable for European settlement, native and European areas sometimes occupy different parts of one natural region which for adequate erosion control requires unified treatment and coordinated land-utilization practices throughout its length and breadth. With the examples from America before us, we can imagine that a position might easily arise in which it was imperative to reserve definite areas for forest, for controlled grazing, for plantations, for food production, for retirement from cultivation and so on, regardless of the colour, status or innate disposition of the present landholders. In such cases the boundaries between native and European areas would ultimately be determined by the nature of the soils, or they would disappear, or native and European agriculture would become indistinguishable.

That is a vision of the future and takes no account of human determination to order things otherwise. Determination in America to build and preserve an individualistic society in which science and capitalism would distribute Nature's abundance to all has been nullified by soil erosion, and there seems no reason to assume that the best-intentioned plans for Africa (where the threat of erosion is more imminent than in America) will succeed unless they are grounded in a deep understanding of the properties and limitations of the soil. Nowhere yet has the conflict between what the ruling race demands from the land and what the land demands from its cultivators led to an open conflict between the conquerors and conquered, but that such may occur in the future is more than a possibility.

It is now clear that throughout East Africa—at least in those territories under British influence—any scheme for permanent soil conservation depends for its success on adjustments in the system of land tenure. The communal occupation of land by a tribe militates against any permanent agricultural improvement. In former times when the tribes were mainly nomadic, maintenance of soil fertility was a matter of little importance. When the tribal land showed signs of exhaustion and before any lasting damage was done, the tribe moved on, securing new land by right of entry or force of arms. The weaker tribes were suppressed and there was always ample land to give exhausted areas time to recuperate before they came again under cultivation or grazing. The communal system of land tenure was well adapted to this mode of existence; the cultivator needed to take no thought for the future, he could exploit his temporary holding to the utmost, a beneficent Nature would warn the tribe when to leave and would restore the land to its former fertility during the tribe's absence. An indispensable condition for the successful operation of tribal ownership was that there should be a large excess of land available over and above immediate requirements. As soon as or even before land hunger became apparent owing to the permanent confinement of tribes to stated areas, the communal system was bound to break down or lead to disaster. It has been maintained to support the principles of segregation, natural native evolution and Indirect Rule, and it has led to disaster. An inevitable consequence of communal ownership is to put a premium on soil exploitation; no year-to-year occupier of land will spend his substance on improvements while there is still a profit to be gained by extracting soil fertility. Similar but slower effects have followed the rapid spread of short-term tenancy in the United States.

To preserve the basic character of African life and to prevent its complete submergence by European civilization, the tribe must remain the social unit. To preserve the soil, without which life is impossible, in the presence of a contiguous European civilization, the systems of land tenure must be profoundly modified. Can the tribe survive that? Sooner or later—and for the sake of the land, preferably sooner—the foundations upon which African social units have been built will have to be reconstructed,

and it is scarcely conceivable that the present superstructures will be able to stand the strain unaltered.

Where a system of individual land ownership prevails, the effect on, and the outlook for, the soil is not much better than under communal ownership, particularly where (and this is not confined to Africa) customs of inheritance result in continuous fragmentation of properties. The more individual properties there are, the more difficult it is to secure adequate co-operation between the landholders. A more fundamental difficulty lies in the African's innate attitude to the land. Land is not so much a form of wealth as a source from which wealth can be produced as from a mine, but with the advantage that Nature will restore the mine to full productive capacity if it is abandoned before complete exhaustion.

A 'land sense' rather than a profound scientific training is required to envisage the necessary measures to be taken to preserve the soil. There are administrators and farmers possessed of such a sense, to whom the vision of a safe and conservative tropical agriculture is becoming increasingly clear, in most European territories in Africa. The chapters on erosion-control measures show that there is nothing magic about safe farming; most of the operations involved in it have been practised in one form or another from time immemorial. From the economic standpoint erosion control should be simpler in tropical than in temperate countries; labour is cheap, the soil brings forth crops with the minimum of cultivation, and tropical produce is not subject to quite the same intense international competition as is much temperate produce. The difficulties of applying erosion control in Africa are not technical, but psychological—how to instil a real land sense into a multitude of primitive people while at the same time imposing upon them an agriculture foreign to

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42 *a*. North Dakota, U.S.A. Reservoir for water conservation. Earth fill with rubble masonry and paved shoot. See page 196.
42 *b*. Utah, U.S.A. Terrace-trenches being finished after machine work has been completed. Dams are placed in terraces to form individual reservoirs. The trenches are designed to hold the rainfall until the water seeps into the ground. Terracing facilitates plant growth by catching and storing run-off. See page 196.

the natural instincts by which they still live. Nothing reflects the character of a primitive society so clearly as its agriculture. Nothing is more difficult to change than agricultural customs and organization without destroying the foundations upon which the society is built.

A witness before the Kenya Land Commission gave his opinion that 'the African people have never established a symbiotic relationship with the land. They are, in the strict scientific sense, parasites on the land, all of them'.[1] This sweeping statement is at first somewhat difficult to reconcile with the fact that erosion is most widespread and severe in European colonies like Kenya and Southern Rhodesia. There is, however, a good deal of truth in it in the sense that the African has no instinctive love for land as such, at all comparable with that exhibited by Europeans. Land does not give the owner a secure anchorage (which in most cases he does not want) nor is it regarded as a mark of social standing. Pride of possession goes to the produce of the soil and particularly to cattle which are more easily moved than the land that nourished them. Overcrowded and ever-multiplying cattle, sanctified in the role of currency, are the main direct cause of erosion in the areas where natives are confined and protected from natural eliminating scourges. Efforts to relieve overstocking by inducing natives to accept coins in place of cattle as tokens of wealth have not yet been crowned with much success. It is questionable, too, whether merely removing this, to Europeans, apparently insensate love of worthless cattle without substituting for it a genuine but, to the native, quite foreign love of the land will act at best as more than a temporary palliative. It should be borne in mind that

[1] Quoted in *Nature*, vol. 141, 1938, p. 397.

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43 *a*. Kansas, U.S.A. Lister furrows filled with water on the morning following a two-inch rainfall. See page 186. 43 *b*. Nebraska, U.S.A. Basin listing on the contour. Originally there was snow on the field but it thawed, leaving water in the eight-foot-long basins. During the night it would freeze again and next day the thawing of the ice and soaking-in of the water would continue. It is probable that there was practically no run-off on this field during the winter. See page 186.

outside Africa the universal passion for metal and paper tokens of wealth in preference to land has been the root cause of most man-made soil erosion.

Furthermore, should the natives become susceptible to the charms of money they will presumably want to produce more for export—a procedure unlikely to benefit either the soil or European traders.

The native's idea seems to be to produce enough from his land for his family to live on and to convert any surplus into stock which he can take with him when the time comes to move from the exhausted land on to fresh fields and new pastures. The several native systems of land tenure have been evolved for this purpose, and with disease and war ensuring stationary human and animal populations they worked well enough before European settlement. The system gave no encouragement to land improvement, which in any case was unnecessary when land was plentiful. Nature restored depleted fertility more quickly and efficaciously than any native cultivator could have done. But the success of the systems, whether based on communal or individual ownership, depended upon ample land being available for migration and on a passive submission to the authority of the soil and vegetation—two conditions which are incompatible with an advancing civilization.

Where conditions of land tenure appear to have encouraged erosion or militated against its prevention, it is probably not the system that is at fault so much as the psychological attitude towards the land of the people who evolved the system. The people are still mainly in the migratory stage of development and have little attachment to the soil. Until they develop a greater love of, and establish a real 'symbiotic relationship' to the land they will not willingly hold or cultivate it in order to conserve it. The European invasion has forced the naturally migrant population suddenly to adopt a settled existence but has not succeeded in effecting a correspondingly drastic change in the natives' scale of values. It remains to be seen how far and how quickly the native can be 'educated' to love the land and whether coercion, which in some degree seems inevitable, will promote the education. Assuming that European civilization has come to stay, circumstances will compel the natives to

evolve methods of land utilization compatible with a settled existence, and the real question is whether their natural detached attitude to the land can change quickly enough to avert the alternative disaster of the desert's encroachment.

On the island of Ukara in Lake Victoria the Bakara tribe has been forced by the circumstances of its isolation to adopt a farming system which will give continued support to a dense settled population. Here economic pressure has resulted in the evolution by the natives themselves of a conservative agriculture which includes crop rotations, green manuring, stall-feeding stock, use of farmyard manure, and pit cultivation and contour ridging. Land tenure is individual. Soil erosion occurs but is not unmanageable and is indeed remarkably slight considering that much of the land is under almost continuous cultivation. Similarly, the Erok, Wamotengo and Wakara people, geographically isolated, deprived of the limitless. bounty of Nature and untouched by European influence, evolved their own systems of soil conservation. The timid Erok were confined to a limited area by pressure from the more virile, warlike tribes surrounding them. To-day 'the Erok, no longer afraid, is content to cultivate and move on; he has become a miner instead of a farmer'.[1]

The Bakara, however, were not suddenly isolated from the mainland. The evolution of their conservative agriculture was a normal and gradual process of the survival of the fittest under gentle coercion from Nature. Much stronger coercion will have to be applied to force the natives in contact with European civilization into a similar mould in the short time still left to stem the swelling tide of erosion. They cannot, in fact, be left to work out their own destiny; they require something in the nature of a far-sighted despot who will see that his own fortunes are bound up with those of his subjects. Coercion, which need not be oppressive, will be required to ensure that all or the majority of native landholders protect their soil in the interests of the community. The results of soil protection may be sufficient in themselves to cause a change of heart and make a bond between the native and his land that will be a safeguard against subsequent exploitation, but more probably continued pressure will have to

[1] B. J. Hartley in *East African Agricultural Journal*, March 1938, p. 391.

be exercised to quell the dormant migrant instinct which trusts to Nature to look after the soil. It may be necessary to tie the native by force or persuasion to the soil until such time as he is prepared to stay of his own free will.

The feudal system of land tenure characterized that period of European development when men were not entirely masters of the soil—when the forest was still a co-dominant ready to repossess the land immediately it was abandoned. A somewhat analogous ecological relationship between man and vegetation exists in Africa to-day, and a system of land tenure analogous to, but not identical with, medieval feudalism might well develop as a way out of the impasse created by soil erosion and the conflicting demands of the indigenous and exotic races on the land. The scales are tilted against the natives in favour of the vegetation. The Europeans, on the other hand, have the inherited experience of civilization to help them and the untried but powerful weapon of science which may bring victory or defeat according to the use that is made of it. Except in certain restricted areas, however, they are constitutionally unfit to make permanent settlements. The land, if it is to be permanently settled, requires a master to control it and servants to work it. In Africa, as a rule, those who could be masters are incapable of heavy work and those who might be servants are incapable of ruling.

When soil erosion is the immediate consequence of any misuse of settled land, the security of the community or State depends upon the landholders' appreciation and fulfilment of their separate responsibilities, and their submission to certain conditions. Some conditions—e.g. that soil fertility be maintained however the land is used—are of general application, others—e.g. the permissible types of land utilization—are specific according to the location of the land, the soil type, climate, etc. Where the stability of each field depends upon that of its neighbours some kind of regional or district organization becomes imperative, and the more independent landholders there are, the more difficult it is to organize and carry through a permanent soil-conservation plan. We suggest that some system which will leave the responsibility for organizing, and the power to enforce, soil conservation in the hands of the few while

the many do the work either voluntarily or by indenture is indicated as the probable future basis of land tenure in tropical Africa under European influence. In every way the European is fitted to be the overlord and the native to be the villein.

Feudalism in any form—twentieth-century African feudalism would be very different from the medieval variety—is contrary to Britain's expressed policy with regard to her colonies and protectorates, but that policy has not been outstandingly successful in its effect on the welfare of the land, which is now demanding prior consideration to the welfare of the people. The expressed object of French administration is, by contrast, to exploit the colonies and their inhabitants for the benefit of France and Frenchmen. The colour bar is not so insuperable between French as between British and African, and racial segregation and 'holding the land in trust for the natives' have never come to the fore as practical policies in French possessions. The extent of soil wastage in French Africa is largely a matter for conjecture; its presence has not been proclaimed so loudly as it has been in British Africa, and probably it is not so widespread or advanced, for geographical reasons. (Erosion is much more serious in East than in West Africa.) In view of the innumerable other factors involved, it would be useless and invidious to try to trace a connexion between the present extent of erosion and the prevailing type of administration.

The fact that erosion has occurred and is occurring through practically all tropical Africa under European administration is sufficient indication that no colonial country has yet discovered the correct relationships that should exist not only between the different races but also between these and the land. Colonial policy has been concerned primarily with adjusting the immediate conflict of interests between the rulers and the ruled. The land has of course come into the picture, but only incidentally to the more urgent matter of keeping the peace between men. The position is now being reversed; the demands of the land must and will be satisfied, if necessary even at the cost of peace. It will be a supreme triumph of statesmanship if at least something of European civilization remains intact after the land has been made, or has made itself, secure.

A feudal type of society in which the native cultivators would

to some extent be tied to the lands of their European overlords seems the most generally suited to meet the needs of the soil in the present state of African development. Africa cannot be expected to accept feudalism without a struggle; in parts of British Africa it would mean jettisoning the promising experiment of Indirect Rule, everywhere it would mean denying to the natives some of the liberty and opportunities for material advancement to which their labours should entitle them. But it would enable the people who have been the prime cause of erosion and who have the means and ability to control it to assume responsibility for the soil. Self-interest, untrammelled by fears of native rivalry, would ensure that the responsibility was carried out in the ultimate interests of the soil. At present, humanitarian considerations for the natives prevent Europeans from winning the attainable position of dominance over the soil. Humanity may perhaps be the higher ideal, but the soil demands a dominant, and if white men will not and black men cannot assume the position, the vegetation will do so, by the process of erosion finally squeezing out the whites. For the tropical environment is so delicately balanced that the soil must have a firm ruler, or chaos will supervene—as it has already supervened in Africa.

It is a rule in the economy of plant associations which can hold the soil secure against erosion that the subordinate species exist for and by favour of the dominants. The undergrowth in a forest gets the light and food which the trees permit. It is kind to the undergrowth to remove the trees, but hard on the soil, for the undergrowth can seldom prevent erosion or soil exhaustion in the absence of a tree canopy, and the whole environment suffers.[1] It is kind to the natives to allow them their due rights in a civilized community but hard on the soil, and soon in Africa the soil will be more insistent on its right to have a ruler than the natives are on theirs. Either the white man or the wild vegetation is destined to become dominant on the soils which the former now administers but does not rule.

The end of ecological evolution has not come when the dominance of trees is firmly established on a forest soil. There are forests in which the undergrowth disappears completely as

[1] The relation between a tree canopy and the erodibility of a natural forest soil is explained on p. 97.

the tree canopy closes; there are others in which the dominant trees and undergrowth exist indefinitely in equilibrium; and there are others in which the undergrowth thrives best and ultimately displaces the trees. What happens depends largely upon the soil. What will happen in Africa if and after the white man has won his dominion will also depend upon the soil. He may become the supreme overlord of tropical Africa but, except in very limited areas, the soil and climate will always favour the black man.

For better or worse, the seeds of civilization have been sown, and Africa can never revert to its former condition, where the forest, savanna and veld maintained the stern and efficient laws of the jungle. Is it to be a white, a black or a mulatto civilization, or are white and black to work out their separate destinies side by side? The choice, if it rested entirely with the ruling people, would be between the first and last, but the ruling people are still subservient to the soil and the treatment they have accorded to the soil has not been such as to strengthen their control over the destiny of the continent. Soil erosion is precipitating a decision which might well have been deferred until all men in Africa had gained wider experience, and soil erosion will in the end negative any decision except the right one.

CHAPTER XXI

Political and Social Consequences
IV. South Africa

South Africa's immense underground wealth and poor surface soils. The dependence of white civilization on soil fertility. How the soil may be saved. Political obstacles to co-operation. Conserving soil with gold. Government assistance and farmers' indifference. The 'poor white'. A soil-exhaustion policy after the Boer War. Soil conservation by importing grain. Subsidizing the farmer or the soil? Racial considerations. Native land hunger. The Transkeian Territories. Vital areas in native reserves. Basutoland. Educating natives in soil conservation. The position of the native in industry and agriculture. More native land is inevitable. Difficulties in distributing the country between natives and Europeans. A possible way out.

A national catastrophe, due to soil erosion, is perhaps more imminent in the Union of South Africa than in any other country. From the political and social point of view the erosion question in South Africa has several unique features.

The enormous underground wealth of South Africa has been the principal inducement to European settlement and the principal means by which European civilization has entrenched itself in the country. The operating gold mines are, however, within sight of exhaustion and the still untapped sources of gold are unlikely to be of great extent. The surface wealth as represented by the natural richness of the soil is, on the other hand, small and has in the past been mercilessly exploited by farmers and landowners attempting to maintain the standard of living set by the white mining community. The still continuing loss of soil by erosion constitutes a much more serious threat to South African prosperity than the exhaustion of the mines, which was

inevitable whatever happened. It is not sufficient to stop the rot of soil erosion. Already there is little excess of fertility to permit an expansion of population without a fall in the level of subsistence, and if the population continues to expand at its present rate there can be little doubt but that the better adapted native races with their lower demands on the soil will squeeze out the more exacting exotics. It is imperative not only to stop erosion but also to restore the soil fertility that has already been lost. If human ingenuity can achieve that, there seems no reason why it should not then raise soil fertility further to a level hitherto unattained. Given a stable and productive soil, Europeans should at least be able to hold their own in competition with the natives; without soil stability they are doomed to occupy at best a subordinate place in South Africa's economy. A clearer illustration cannot be found of the dependence of a civilized society on securing and maintaining absolute control of the soil.

The means by which control of the soil can be secured are ready to hand. The present technique of applying them could and doubtless will be improved, but is already adequate to prevent a major disaster, expecially if common sense is allied to the rapidly advancing science of grassland ecology. 'Let us project ourselves twenty-five years onwards in time', wrote a contributor to the Bloemfontein *Friend*,[1] 'and imagine that, in the interval, throughout the grazing and arable areas of the Union —European and Native—soil and water conservation work combined with pasture cultivation has been carried out systematically on every sluit and donga system....

'Let us imagine, too, that cornlands, pastures, valleys exposed to the threat of flood in seasons of heavy rainfall have been in the same period protected with contour furrows; that veld burning on the mountains has been stopped; that progressive reclamation work has restored to some measure the absorbent qualities of the vegetation of our catchment areas.

'Let us conceive, further, that wise policies of land management, backed by seasonal weather forecasts, have in the same period established a better balance between stock farming and crop farming; and that there is no longer serious overstocking to cause fresh trampling out of veld.

[1] February 25, 1937.

'Can it be doubted that the soil of South Africa would then be capable of sustaining a population at least double its present total and that the foundations of our sometimes precarious civilization would be deep and secure in a prosperous, well-watered land from which the spectre of drought was banished?'

This vision should be realizable by a nation financially in a position to ignore the costs of erosion control, equipped with all available aids of modern science and faced by an unthinkable alternative if the emergency is not immediately tackled. The difficulties—some of them perhaps insuperable—in the way of its realization are largely political; when General Smuts said that soil erosion was 'bigger than any politics' he was addressing a people among whom politics is a particularly powerful, and powerfully disruptive, force. British, Dutch, Africans and Indians are quarrelling over the share-out of the South African skeleton after it has been finally stripped, and in such an atmosphere the technically simple process of re-clothing the skeleton so that all might feed to repletion does not receive due attention. Unavoidable political passions and antipathies are still strong enough to restrain the co-operative spirit which, in South Africa as elsewhere, must form the basis of a national soil-conservation policy.

But it is a race against time. Without its mineral wealth South Africa would be a parched land without hope of recovery, for men do not reclaim a semi-desert for amusement. It was not always such a parched land. Seventy years ago a traveller stated that the greatest obstacles to pastoral farming in the Orange Free State were the natural richness and excessive wetness of the pastures. The rich grasses have now gone and the dried-up pools and springs are remembered only in place-names like Bloemfontein. The same amount of water as formerly falls from the sky, but it tears new gullies through the land, sinks into the bowels of the earth or finds its way into the sea without nourishing the plants to which it should have given life. The former conditions can be restored, the water can be held on the land so that a rich vegetation reappears and re-forms a naturally absorbent soil, but for men to work the transformation they must find money and be prepared to spend it without hope of immediate return. What better use for South African gold could

be found than to bury it again in the surface soil? South Africa might re-purchase much of her lost fertility with the wealth lying beneath the soil, whereas many other African countries must buy fertility with the produce of the soils themselves—a case of robbing Peter to pay Paul—or accept the wherewithal as a gift or loan from elsewhere.

It is worth noting that the Government provided about £2,500,000 in the way of subsidies for soil-protection works during the four years 1935–1937, which may be compared with a gold production valued at about £300,000,000. The relative smallness of the government grant was not due to official parsimony but partly to the inappropriateness of the proposed scheme, and largely to the indifference of farmers. A section of the farming community is fully alive to the need for action but a 'deplorably large number of farmers, illiterate and steeped in the improvident habits of generations of similar ancestors, remains blissfully unaware of the ravages of erosion or official efforts to get at them, or declines to interfere with "acts of God" '.[1]

The lack of recognition of, or indifference to, the consequences of soil exploitation on the part of a large section of the dominant race introduces into South African erosion policy a disturbing factor that is almost absent in tropical Africa where the European settlers have fewer axes of their own to grind and their average standard of education is higher. One of the soil conservationist's great problems, indeed, is the presence of irresponsible 'poor whites' and illiterates on the land—a problem that extends in lesser degree beyond the frontier into Southern Rhodesia. Professor H. D. Leppan in *The Organization of Agriculture with Applications to South Africa*,[2] has expressed the somewhat heterodox opinion that the land is overstocked with men as well as with animals and that a white peasant class is undesirable. Needless to say, this opinion is not universally held, but it may be compared with the arguments put forward in the last chapter to show that the future trend of social development in tropical Africa may be towards feudalism. We shall return later to the application of these arguments to South African conditions.

[1] A. W. Phillips, *Farmer's Weekly*, February 26, 1937.
[2] Central News Agency, Johannesburg, 1936.

There is much more general agreement with Leppan's view that in a policy of land utilization concentrating almost entirely on properly organized animal husbandry lies South Africa's chief hope of salvation. He traces the past policy of encouraging cereal production, assisted by export subsidies, tariffs and a magnificent elevator system, to the economic consequences of the South African war, and points out that the reverse policy of encouraging cheap grain imports would have the effect of increasing soil fertility, thereby helping to save the veld from erosion. The imported feeds would be used to relieve pressure on the pastures, and not to carry more animals, which should be fewer and of better quality. More use should be made of cultivated land in producing animal rather than human food. The meat market could be enormously extended, and the demand for maize proportionately reduced, by educating the natives and raising their standard of living.

A positive policy of encouraging imports into a country which could, if desired, be self-sufficient in respect of the main cereal crops would be unique in the modern world. The adoption of such a policy would support the argument we developed in Chapter XVII that erosion and economic nationalism are complementary forces causing a gradual, if painful, re-distribution of soil fertility throughout the world. In many of the newer countries it will be sufficient to conserve the remaining fertility by an externally enforced restriction of agricultural exports, but in South Africa the present standard of fertility will be inadequate to support a white civilization when the mines are exhausted. Before that happens inherent fertility will have to be implemented by imports, and the importation of food, particularly animal food, much of which will ultimately find its way into the soil as manure, is one very obvious way of storing up a reserve of fertility in the soil. On the face of it, too, a direct exchange of some of South Africa's abundant gold for soil fertility from another land would seem a good bargain. But farmers are more likely to demand that the country's ephemeral surplus wealth be used for the fatal purpose of subsidizing production for export.

The disharmony between urban and rural life—between the wealth of the mines and the poverty of the soil—is a matter

of growing concern to all shades of South African opinion. A more even distribution of the nation's money resources would go far towards mitigating the present antagonism between town and country, but by itself would not necessarily operate in favour of a more conservative agriculture. From a practical point of view the crux of soil conservation is controlled veld management, without which all economic and political measures are useless. The very fact that controlled veld management, however carried out, involves first and foremost the conservation of soil fertility implies that it will also involve some immediate financial sacrifice (which can be alleviated by a subsidy) on the part of the farmer. The farmer has to realize, for example, that the improvement of his pastures, at his own or the Government's expense, is not to enable him to keep more stock; he may even be compelled to keep fewer when his land is a national asset than he could when it was a liability.

The danger in granting financial assistance to the countryside is that the money will be used primarily to appease the recipient and to recoup him for past losses and only secondarily to restore the soil. Indeed, a common criticism of the Government's first tentative schemes for subsidizing anti-erosion work has been that the lure of a subsidy for damming, and not land reclamation, has been the main incentive for undertaking the work, which is consequently not always carried out with due regard to its real object. Both the farmers and the land are crying out for help, the former the more vociferously, the latter the more insistently. Perhaps the Union can afford to satisfy both; if not, it would be short-sighted policy not to give preference to the land. Very clearly, there are gigantic political obstacles to be overcome before a consistent policy for rehabilitating the soil can be carried through to completion, even if we ignore the all-pervading racial questions.

Ecologically, racial antagonism in South Africa differs from that in tropical Africa in that climate and altitude allow permanent European settlement over the greater part of South Africa. There are no insuperable physical obstacles to prevent a European people from running the country in the entire, or almost entire absence of natives, as white Australians run the physically more unsuitable northern part of Queensland.

Actually, however, European domination in South Africa is producing a greater increase in the native and Asiatic than in the European population. If, as seems probable, the relative rates of increase continue to favour the natives, provision must be made for the future extension of native areas over land at present held by Europeans. There is no knowing where this process would stop; the possibility that the Europeans may gradually be squeezed out of their land by sheer weight of native numbers is a powerful argument against the policy of racial segregation.

The land hunger which now afflicts the natives and makes further concessions of land inevitable is due at least as much to erosion and decreasing soil fertility as to increasing populations. That erosion has been disastrous in many native reserves and has made them unfit to support the people within their confines is generally admitted. We may quote from a memorandum[1] prepared by the Chief Magistrate of the Transkeian Territories to illustrate the conditions now typical of many reserves. The Transkeian Territories cover over 16,000 square miles, contain about 1,000,000 humans, 1,500,000 cattle and 4,660,000 small stock.

'Prior to the coming of the European, the native was a nomadic hunter and pastoralist; he produced very little from the soil. Within recent years his mode of living has completely changed. He is now primarily an agriculturalist and secondly a pastoralist. In other words he exists mainly on mealies grown by himself and regards his cattle as wealth negotiable only in times of dire need.

'He has increased considerably in numbers and the Territories can now be said to be overpopulated and overstocked, the latter condition arising out of the former.

'To-day the general appearance of the Territories presents the following picture:

'(1) Grazing grounds are largely trodden out, seeding rarely takes place and quality of grazing is seriously impaired.

'(2) Every available foot of arable land is used. Lands have been badly located and frequently occur on very steep slopes.

'(3) Indigenous forests and bush have largely disappeared.

[1]From *Erosion Soil and Conservation*, by G.V. Jacks and R. O. Whyte, 1938.

'While the number of stock per acre is far in excess of what it should be, the fact remains that the number of stock per family unit is barely sufficient for its needs if an average is taken per family.

'The anti-erosion works which have been carried out will help, but native customs and mode of living render effective reclamation measures exceedingly difficult.

'Only the following drastic steps will solve the problem:

'1. Reduction in the number of stock, which is not a feasible proposal.

'2. The purchase of additional land to alleviate the over-population.

'3. A definite scheme of stock and grazing control.'

The position is equally serious in other reserves which cover some of the best watersheds and basins of the principal irrigation rivers. It has been particularly unfortunate that the Eastern Highland region, owing to its high temperatures and rainfall, is the least healthy for European settlement while at the same time it contains the sources and headwaters of the Union's main rivers. It was only natural that these high lands should have been reserved for natives in preference to the lower lands in easier communication with the centres of industry. But the high lands control the water regime of entire river systems, and it is from the deforested watersheds that the germ of infectious erosion spreads to distant regions. Without adequate watershed protection regional erosion control is doomed to failure. When a formerly nomadic people, pastoral or agricultural, is confined to a restricted forested area, extensive deforestation is inevitable. Political boundaries mean nothing to a turbulent river whose headwaters are uncontrollable, at one time pouring its floods over the plains and valley floors, and at another leaving dry its bed and the associated springs and wells. An old Japanese proverb says that 'to rule the mountain is to rule the river'—and to rule the river is often to rule the country. The natives on the watersheds hold the key to the security of the lower-lying land. It is in their own as much as in Europeans' interests that they should be educated in the art of protecting their land, and under enlightened guidance they may yet succeed in devising some

system of land utilization which will at once enable them to satisfy their bodily needs and conform to the safety limits imposed by the environment. Enlightenment must necessarily be a gradual process and as time is short it may have to be supplemented by coercion on a scale not hitherto attempted. At least the very strictest control will have to be exercised over the use to which these native-owned watershed areas are put, for the ultimate benefit of the owners certainly, but more urgently for the safety and welfare of neighbouring and distant regions intended for the permanent homes of white men.

This aspect of soil erosion is well illustrated in the Basutoland Protectorate, completely enclosed by territory of the Union of South Africa. This bone of contention between the British and South African Governments is usually regarded from the British point of view in the light of the declared policy that the interests of the natives are paramount, and there can be little doubt that the majority of natives would prefer a protected autonomy under the British Government to absorption into the Union. The Union's demand for absorption has admittedly been actuated mainly by nationalistic sentiments—no independent nation gladly submits to territory, which is geographically part of the nation, being under control of an external administration.

Basutoland contains the dominant watershed in South Africa and through it run the headwaters of the great Orange River and its tributary the Caledon. South Africa's principal source of water is controlled from Basutoland, and in South Africa water is of more than usual importance as there is scarcely enough to

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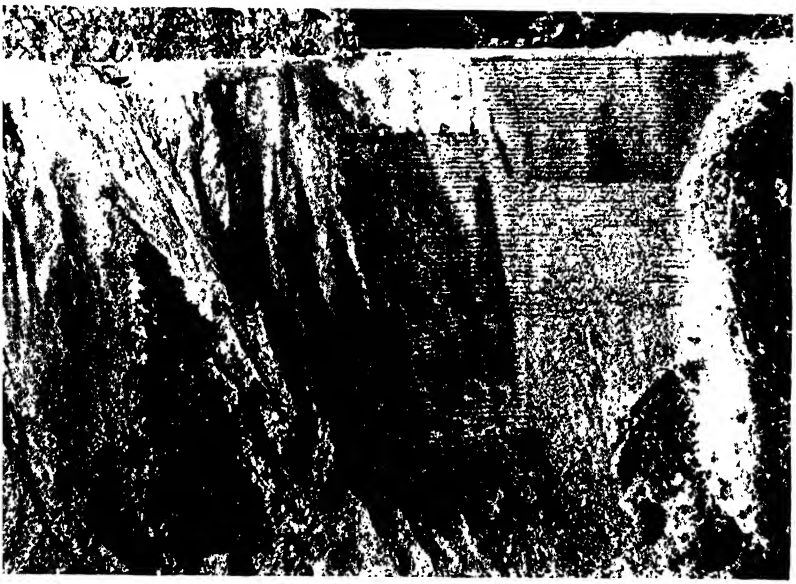
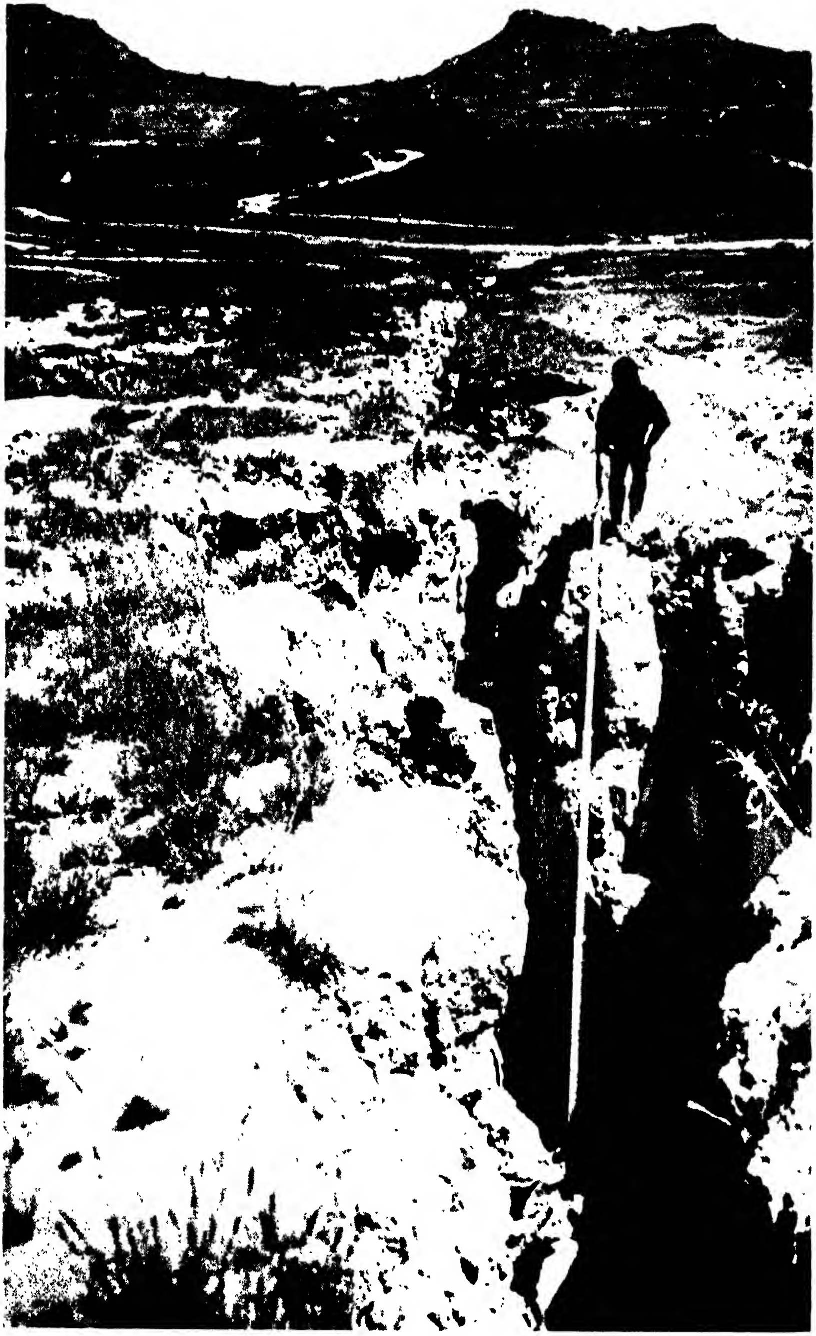
44 *a*. South Africa. Typical contour draining of a road near Bothaville in the Orange Free State to prevent erosion. See page 199. 44 *b*. California, U.S.A. An erosion-control crew in the process of controlling a large road slope. To the right the slope has been treated by a system of contour wattles imbedded in the soil and supported by wooden stakes and live cuttings of willow, elderberry, etc. In the centre the crew is working towards the top after previously smoothing out gullies and combing down loose rocks. To the left is a section of a slope before it has been smoothed or controlled. Erosion from such slopes occurs at the rate of 100,000 cubic yards per mile. See pages 200-1.





go round. The occupiers of Basutoland could, therefore, to some extent hold South Africa to ransom in the same way as the occupiers of the Sudan can hold Egypt to ransom. It is to the manifest advantage of the Basutos that they should organize to prevent erosion on their own land and the consequent disasters to Union territory, but an organized native community in which man had become the undisputed dominant over the land would be in a strong position to determine its own destiny.

These are matters of growing importance to the people in the Union. For some years the Union Government has followed the policy of acquiring watershed areas for soil protection, and the people look to the British Government to make that policy effective by adopting similar measures, where necessary, in the Protectorates. The British Government, on its side, recognizes the urgent need for immediately preventing further erosion and restoring as far as possible the derelict areas of Basutoland in the interests of the inhabitants, and financial and other assistance is being given for the purpose. A Report to Parliament on the financial and economic position of Basutoland[1] stated that 'erosion in its many aspects is now the most immediately pressing of the many great problems which confront the Administration'.

Thus erosion control is slowly coming to be recognized as paramount over native interests. The ultimate interests of the natives should not clash with erosion control, but their immediate interests, which are politically the more important, may, and if they do, they must yield before the needs of the soil both within and beyond the Protectorate's frontiers. Since the consequences of erosion extend far into Union territory, the Union has acquired a powerful lever with which to advance its claims for absorbing Basutoland.

One beneficial result of the political status of Basutoland has been not only to draw attention to the urgency of erosion control on native lands but also to convert attention into action.

[1] H.M. Stationery Office Cmd. 4907, London, 1935.

45. Basutoland. Erosion of a donga caused by a short-cut path. The staff is fourteen feet long and is not touching the bottom.

We cannot say whether the British Government needed its hand forcing in the matter, but it can scarcely be doubted that pressure from the Union expedited the official machinery which had to be started six thousand miles away in a country where the disaster of erosion has not been experienced. South Africans naturally have a more realistic appreciation than the British of the imminence of the erosion danger. Now a kind of rivalry is apparent in the conservation policies of the Union and the Protectorate, each aiming at giving the natives the best deal compatible with the safety of the land. It is felt in the Union that if the Basutos observe a steadily increasing prosperity in the native reserves adjoining their country their attitude towards incorporation into the Union may be modified. Those who sympathize with the Basutos' present opposition to incorporation are recognizing that their position can only be maintained so long as it does not threaten or inflict damage on Union territory. To the South African the security of his hold on the land is more important than the interests of the indigenous inhabitants; the London administrator is pledged to consider the latter first. The political status of Basutoland guarantees that among the conflict of interests which can take little thought for the distant future both land and people shall receive a fair meed of consideration. They are an indivisible unit—as is freely admitted in theory. It is fortunate that circumstances should compel the fact to be recognized in practice.

It should be mentioned that hitherto no coercion has been applied to force the natives to conserve the soil, unless temporary closures to grazing are regarded as coercion. Every encouragement, however, is given to the adoption of conservation measures. Demonstration of the beneficial results of soil conservation usually has a very good educative influence on the natives who in some districts are now beginning to ask for contour banks and other anti-erosion works to be carried out on their fields. But there is still an enormous inertia to be overcome —an inertia that is not so much an expression of indifference as

46. Wisconsin, U.S.A. Cock pheasant and red-wing blackbirds at a winter feeding station built by the Soil Conservation Service. See Chapter XVI.

a reaction against a mode of life foreign to native instincts. There is little doubt that, given time, patience and foresight, the native would accept the dictates of modern agriculture, but education is not making such rapid progress as erosion in native reserves.

Time is the essence of the problem. In the towns the native has been forced into the modern industrial mould, has released himself thereby from the restraints of tribal custom and has accepted a heavier yoke of servitude. The transformation of the native into an industrial worker cannot be regarded as a social triumph, nevertheless industry is firmly established and prospers on what is essentially indentured native labour. The position of the industrialized native, working for a low wage at unskilled labour and unable to rise, is not a satisfactory one, but only by putting and keeping the native in that position could the country's mineral wealth have been exploited while its control was retained in European hands. Is it possible that the European can remain on, and at the same time preserve, the soil only by imposing a similar enforced servitude on the rural native?

One should not draw too close an analogy between the state of agriculture and of industry. A national industry such as mining can be built up and reach its maximum development in a few years or decades; the evolution of agriculture has, in the past, always been slow and gradual, since, unlike the development of industry, it is a biological process. Recently settled countries have made what is now recognized as the cardinal mistake of adopting many of the principles of a fully evolved agriculture. The consequences have probably been more disastrous in South Africa than anywhere else and necessitate an immediate revolution in agriculture, i.e. in the relations of men to the land. The alternative to going back to the beginning and reverting to indigenous native farming methods and the complete destruction of civilization is a rapid, thorough and far-sighted re-organization of agriculture with soil conservation as its basis. Such a re-organization might be compared with the nation-wide emergency organizations now being set up in Europe

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47. Missouri, U.S.A. This earth fill is forming a pond that will be the centre of a wild-life refuge. A terraced field empties into the pond. See Chapter XVI.

under the threat of war. In South Africa the threat has become a reality whose nature is known, but both in South Africa and Europe speed, efficiency and foresight are the indispensables. No European administration dares hand over the organization of national defence to the lowest and least educated strata of society or even let them have a voice in the matter. In South Africa the soil has already declared war on European civilization, and no half measures can be permitted in coping with the situation.

Neither speed, efficiency nor foresight, in the common sense of the terms, is characteristic of the South African native. Hence his inability, apart from social and political obstacles, to take any but a subordinate position in industry. The rural native has enjoyed wider opportunities in a milieu where he is more at home and where the standard of efficiency necessary to maintain a free existence has hitherto been relatively low. The milieu has changed, however, and for a time at least the occupier of the land, whether landlord or journeyman, must play his part in running a stereotyped machine built to repel the advancing enemy soil erosion. The natives are indispensable cogs in the industrial machine but would break the mechanism if utilized in any higher capacity. It might theoretically be possible to substitute some other type of industrial machine with other purposes than the present one, in which the natives could have freer scope, but there is little choice of type for the agricultural machine which must forthwith be devised for the purpose of saving the soil. We can only visualize the broad outlines of this machine in the phrase *controlled veld management*, but what chance of freedom has the native—or even the illiterate white—where enduring submission to a harsh environment that is being transformed into a safe abode for the fittest and most efficient of the dominant race is the strict order of the day? In his life-and-death struggle with Nature, the white man cannot show much consideration towards underlings.

To control the veld by such straightforward means as restricting or forbidding grazing and cultivation, reducing livestock numbers, ridge-terracing, protecting watershed areas, etc., involves the strictest supervision of all land use so that no occupier, by neglecting his primary duty to the soil, shall steal a march on his neighbours. In the initial stages of executing a soil-

conservation plan restrictions causing serious loss of freedom need not be imposed, and if the plan could evolve gradually towards its later stages subsequent restrictive measures would be mollified and would be accepted as natural by the people. But when the plan has to be carried through at revolutionary speed, there is no time for humanity to adjust itself leisurely to the new conditions; white and black cannot be left to find their relative social and economic levels by developing along their own lines. The crying need of the rural natives is not for money or position but for land, and always more land as their numbers increase and the fertility of their present over-populated areas falls. The natives' land hunger strikes at the root of the soil-conservation problem. It must be satisfied, and every cession of land means a diminution of European influence over the country, unless, of course, the natives occupy their land under the strictest European surveillance, which is not likely to be given altruistically.

We imagine that something like this will happen. The natives will get more land, but the ruling whites will insist on exercising an increasing degree of control over its use, partly to retain their hold on the country and partly to ensure that the soil does not go the same way as in the now eroded reserves by the general or individual adoption of farming practices other than those decreed by Nature as necessary for the security of a white civilization. In particular the vital watershed areas formerly relegated to the natives as unfit for European occupation must revert in large measure to the dominion of forest and grass under European protection, while the displaced natives must be found new land elsewhere. Were the safety of the land alone in the balance, the ideal distribution might be to allot the valley lands to the natives where lack of skill could spread least harm, and entrust the difficult key slopes and mountain tops to the scientific management of Europeans. If black and white are to work out their separate destinies side by side Nature in the end will determine the distribution of colour and any resistance to her ordering will be met by destruction of the land.

The solution of this fundamental problem of land tenure by natives and Europeans is bound to be harsh, because it involves the immediate repayment of an immense capital debt to the land. So long as the natives are restricted as regards the areas

they can occupy, it will be almost impossible to prevent overstocking and exploitative cultivation—at least in the all-important immediate future. The most up-to-date methods of soil conservation cannot restore fertility quickly enough to break the vicious circle of overstocking—soil erosion—land hunger—overstocking. General Smuts believes that 'there is only one solution, and that is the *education* of public opinion'. And there are millions of natives to be 'educated' to an entirely new outlook by a handful of administrators whose other duties are manifold. The vicious circle will probably be broken forcibly at its most vulnerable point—land hunger. The natives might occupy the entire country in order to prevent the destruction that follows their confinement to limited areas, but the soil is demonstrably poorer than it was when it just supported in safety a smaller nomadic population at a lower level of existence. The days of nomadism and trekking have gone for both black and white, and what the land now demands from its cultivators is a settled mode of life with the cultivator a fixed part of the comity of animals, plants and soil that comprise the permanent equilibrium known as fertile land. Without real settlement of the human population that equilibrium cannot be attained. Whoever holds the land must hold it securely and work it for the future, else it will disappear from beneath his feet. The more land there is at the disposal of the natives the less likely are these innately nomadic races to adopt a settled existence and to work the land conservatively. The less land they have the more certainly will it erode under their care; it is indisputable that erosion of native land cannot be stopped by any means unless the existing reserves are greatly enlarged.

Shortage of water sets a low upper limit to the density of population in South Africa. It is at present out of the question that the best watered parts, which could support the densest population, should be reserved for native occupation, but in the end the natural factors of soil fertility and water supply must determine the numerical distribution of the population, regardless of colour. Nature will break down—is, indeed, already breaking down—the boundaries of reserves demarcated with a view to founding a separate European civilization, and European civilization would certainly break down those boundaries

which Nature might have tolerated. The appalling erosion in native reserves has demonstrated the impracticability, under the prevailing natural conditions, of racial segregation. It will, however, require a good deal more erosion yet before that fact is recognized politically.

The alternative to racial segregation and the allocation of specific areas to each race—assuming that European influence is to remain dominant without ruining the country biologically—would appear to be the development of some system of land tenure whereby absolute control of all the land is vested in that class (of the dominant race) which shows itself capable of organizing for the perpetuation of conservative land utilization and of appreciating that its individual and class interests are bound up with the future security of the soil. Appreciation of this fact grows as erosion proceeds. The political strength of the class grows also, but it will remain a small proportion of the European, and an infinitesimal proportion of the total population. Land under the control of thoughtless or impotent individuals will always be a potentially festering sore in the body politic.

With all South African land dominated by such a small and select class, erosion control, *in the mutual interests of the class and the land*, would be a perfectly feasible and straightforward task. We do not suggest that such a state of affairs would be socially the most desirable or that it is at present attainable, but it may be the only alternative to letting erosion complete its destructive work and make South Africa unfarmable. Its attainment would be a gradual process, as the recuperation of the land must also be. South Africa would be possessed by a few powerful European landowners holding their land from the State on condition that they maintained or increased its fertility. The ideal complete landholding would be a river catchment basin or other natural geographical unit. The exceptional susceptibility of the soil to deterioration under improper management allows little latitude in the treatment to which it may be subjected, and whatever may be the reasons, it is a fact that under the present conditions of land tenure it is often impossible to secure adequate coordination between landholders occupying separate parts of a natural land unit.

In this imaginary picture of the not very distant future we can discern the embryo from which a feudal type of society might develop. Probably the South African feudalism would resemble the medieval type more closely than the feudalism we have envisaged for tropical Africa. The natives' demand for land could be satisfied, in so far as was possible under the prevailing conditions of soil, climate and European supremacy, by allowing them to hold land from a white overlord on condition that they worked the land to its own and their lord's advantage. No system of free tenancy would be permissible, for liberty to dispose of land puts a premium on soil exploitation which, once started, is extraordinarily difficult to check, as present conditions clearly indicate. The tenant must be tied to the land to perform his immutable duties of soil restoration and conservation as faithfully and as surely as the animals and plants perform theirs. The South African native faces a period of serfdom as the price he must pay for his share in the benefits of a distant civilization.

It is unlikely that non-landowning whites will submit to the same level of servitude as the natives, indeed it is difficult to see what position they could occupy in the South African countryside except to a limited extent as overseers. Professor Leppan's contention that a white peasantry is undesirable is valid in the sense that a white peasantry is unsuited to the country, at least until the soil has been stabilized and has finally accepted man's dominion. The attractions of settlement in South Africa will wane as existence comes to depend more and more upon the wealth of its exhausted soil. The urban white population now occupied in mining, if it cannot be absorbed in new industries as mining declines, is more likely to disappear by extinction or emigration than to attempt permanent settlement on land where only the born farmer can hope to survive. The white people should increase in power, but decrease in numbers; the opposite fate awaits the black people. Only thus can Nature's harsh harmony, so rudely shattered by the advent of civilization, be restored.

CHAPTER XXII

Conclusion

The severance of mankind from the soil. The purchase of civilization with soil. Soil depletion in the New World and soil repletion in the Old. Economic nationalism and some uses of adversity. Tendencies favouring a redistribution of soil fertility and population. A dense population the best insurance against erosion. Japan and Java. The plunder of semi-arid land. Lack of water limits settlement in the great plains. The early conquest of aridity. The retreat before semi-aridity. Russia's great scheme for conquering aridity. A dream of the future. The American plan of rural reconstruction based on saving water. Australia and South Africa. The tropics. The prospect for Europe.

The respite which, with the advent of the machine age, a large part of the civilized world gained from its arduous primary duty of cultivating the soil has been purchased at great cost. Machines offered to men new lives, at once more lucrative and physically less tiring than agriculture, and started the drift from country to towns that has continued with accelerating momentum to the present time. As the countryside became depleted, machines in the towns intensified the demands made on the land; machines on the railways, roads and seas enabled the increased demands to be satisfied without difficulty; machines on the land took the place of men as cultivators. This accelerating mass production from the land has loosened, and in many cases severed, the biological link between the cultivator and the soil. Formerly, not only the agricultural majority but also the urban minority had a vital interest in each year's harvest; to-day the townsman is virtually unaffected by what happens on the land. If dust storms ruin the North American wheat crop, the Londoner gets his bread from a surplus produced elsewhere or accumulated from previous years. If the

English fruit crop fails, imports increase and neither the price nor supply of fruit is perceptibly affected. The townsman takes at best a dilettante's interest in the land; the delicate balance of Nature upon which the stability of civilization depends can have no meaning to him because he has completely conquered and divorced himself from Nature within the ordinary orbit of his existence. This becomes a serious matter when more than half the civilized world lives in towns. One result has been soil erosion insidiously creeping over the world, and finally and inevitably forcing itself upon the townsman's attention.

Over much of the world the countryman also has lost living contact with the soil, and where he has lost contact erosion has been most severe. In some parts, notably in Africa, men and soil have never formed a true biological unit, but until recently men in Africa did not even claim to be civilized, and the dominant plant communities preserved intact the fertility and stability of the soil. Men were helpless creatures, permitted on sufferance to scratch a living from the earth, but not to rule it. In modern Africa and wherever else erosion has occurred it is found almost without exception that the agriculturist's main object is to live *off* rather than *on* the land, to bleed his soil for the sake of distant towns, and himself to be maintained and enriched by their produce. Farming has become an industry and irreplaceable soil fertility an industrial commodity to be bought and sold and transported to the ends of the earth as easily as any other commodity.

It is only natural that trade in soil fertility should have been towards the great centres of populations and away from the newly settled regions which had more than enough to satisfy the immediate needs of the people. The paradoxical situation has thus arisen that some of the most densely populated, the longest and most intensively cultivated lands find themselves with enormous reserves of untapped fertility, whereas in the new countries, only a few decades after their settlement, hundreds of millions of once rich acres have had to be abandoned to the desert, and men scarcely dare break still virgin land lest a similar fate shortly overtake it. Notwithstanding the huge individual yields that are obtainable with improved varieties, fertilizers and mechanization, average crop yields are falling.

Notwithstanding all the drugs and medicines of modern science, the New World shows signs of growing prematurely senile. The Old World has sucked the life blood which the New World has gladly given and with equal willingness would still give—if it could.

It must be admitted that applied science has been the prime cause of the dangerous state of exhaustion in which many new countries find themselves to-day. Science made the free interchange of goods possible throughout the world; it also found less laborious and more efficient ways of producing bread than by the sweat of the brow. Cultivation of the soil became a means to wealth instead of a mode of life. The more that could be got out of the soil and the less that had to be put back, the better for the cultivator. Europe offered an insatiable market for all that the soil could be made to produce, and science increased the soil's production at the expense of its fertility. Within the space of a century, half the world gained the blessings of civilization, and paid for them mainly with its soil. Never before had the wealth of the soil been so easily extracted. The New World acquired in a few years the fruits of the Old World's thousand-year struggle with Nature. The cost must be counted in failing harvests, spreading deserts, droughts, dust storms, floods, poverty and widespread social unrest on the land, where most revolutions start.

The highly profitable despoliation of the Earth in the nineteenth century brought an enormous increase of wealth in which all parts of the world shared. The boom and slump which followed the World War greatly accelerated the pace at which the Earth was being destroyed, high prices encouraging excessive exploitation of the land, low prices (coinciding with a period of almost universal drought) then intensifying the exploitation of already exhausted soils in futile efforts to make both ends meet. So long as the land yielded fat profits, the restrictive measures which were already recognized as necessary if the soil were to be saved had no chance of being applied. When the slump impinged upon a nationalistic world, the land cultivator soon found that he could not recoup himself for falling prices by increasing production. The impoverished lords of the earth were compelled to forgo the measures which could so easily have

enriched them again, to bribe each other not to produce more than necessary, and by devious means contrary to reason and self-interest to give the dirt beneath their feet a chance to recuperate.

Irresistible political and economic trends which are profoundly disturbing the harmony of nations have begun to exert their influence to redress the balance of soil fertility throughout the civilized world. There are no insuperable technical difficulties in feeding the crowded parts of the earth with the abundant produce of the thinly populated parts. That would be much simpler and more profitable than transplanting the people to where their food is grown (but where usually there is insufficient water to maintain a large population), or than straining at great cost the soil resources of the densely populated countries in attempts to attain self-sufficiency. Yet of these alternatives for ensuring the primary needs of mankind, the first and simplest is demonstrably ruled out; the industrial countries will not receive the produce which the agricultural countries would gladly sell them. Against their own interests the peoples of the Old World are refusing to consummate the rape of the earth. If peace among all nations had been assured, if the League of Nations had fulfilled its purpose, soil erosion to-day might have become an uncontrollable force driving the whole world headlong towards starvation. So long as soil fertility could have been converted freely into money (the reverse is much more difficult), the process of soil exhaustion would have continued at accelerating speed; nothing less than a universal terror of war could stop it. The war clouds gathering over the Old World are checking the march of the deserts through the New, but if they passed away, or if the nations could once more trade with each other without let or hindrance, all the well-laid plans for rebuilding the exhausted earth would be shelved and forgotten overnight. The immediate causes of economic nationalism and soil erosion appear to be unrelated, but the former scourge is quite definitely helping to cure the world of the latter.

The present period of intense nationalism is only the first phase of the process of building up a new symbiotic relationship between civilization and the land. Nationalism scarcely affects the tropics in this respect; it puts a cumulative strain on both

the peoples and the soils of humid, industrialized countries, and it is gradually but surely checking the continuous drain on the fertility of the sparsely settled continental plains. If and when the plains have been stabilized by the evolution of a conservative agriculture appropriate to a semi-arid or sub-humid environment the world may safely indulge in a more generous economy. When that time comes, the ground will have been prepared for the next phase in the re-conquest of Nature. The strain on the resources of the densely populated countries, striving under the whip of nationalism towards self-sufficiency, will become intolerable and we can foresee a great migratory movement from the worn-out moist, to the renovated dry lands—or alternatively a natural decrease of population in the one and a natural increase in the other. If the plains can learn to check the drain on their fertility they should in time be able to reverse the process completely and raise their productivity and population capacity to undreamed-of heights. It has been done in the forests of Europe; it can be done in the plains of America and Russia.

Thus the balance of soil fertility—which is the balance of all life on the land—may be redressed. The Old World cannot give back the fertility it has taken from the New, but it is being compelled to live on its husbanded resources until such time as the New World is restored to vitality and can take over and revive the flickering torch of civilization. No longer will soil fertility be traded across the seas for civilization; civilization will migrate to build up soil fertility, for a stable civilization enriches the earth where it flourishes to a far greater extent than wild Nature can. But the soil demands for its security a dense and settled cover of humanity to replace the plants which men destroy. A perennial plant cover protects the soil better than an annual, which is apt not to be there when it is needed. A farmer tied to his land by necessity or affection keeps a better guard over the soil than the flitting tenant. The denser the plants grow, the keener and more merciless the struggle for existence between them, the less power have wind and water to tear away the soil beneath. The half-starved peasants of Japan know better how to preserve their soils than do the great landowners of America and Australia.

A dense population up to the limit which the land can sup-

port is, indeed, the best insurance against the forces causing erosion. Apparent exceptions to this statement are found in old countries like China and India and in overcrowded African native reserves. China and India, however, are ageing naturally. Their soils are becoming worn out through long use and the erosion that has been proceeding for centuries (though recently accelerated by the intervention of industrialism) illustrates the inevitable mortality of civilization as it has been illustrated in Persia, Mesopotamia and round the Mediterranean shores. The African reserves are eroding because a confined people is still continuing the practices of nomadism.

On the other hand, Japan and Java, two islands with highly erosive topography and climate, supporting 500 and 680 people respectively to the square mile, have got erosion under as complete control as has been achieved anywhere in the world. In neither country has the threat of erosion come suddenly. Both have evolved appropriate farming systems to deal with the menace as it arose. The densities of their populations give every acre of land a national value that may be out of all proportion to its money-earning power. The closely packed and immovable people are compelled at all costs to conserve their soil. 'Conservation' farming comes as naturally to them as, say, mixed farming to Western European peoples; they see nothing unusual or out-of-the-way in taking the necessary measures to keep the soil in its place. They have to face the possibility that economically more efficient methods may make inroads into their national farming systems, but so long as the populations remain high, adequate protective measures against soil exploitation are certain to be taken. Uncontrolled erosion would inflict immediate disaster on the people.

Since the end of the nineteenth century forest protection has been legally enforced throughout the Japanese Empire and an appreciable part of the national revenue is allocated to erosion-control works. Were Japan to find outlets for her surplus population overseas, erosion control might be relaxed in favour of a more profitable and exploitative type of land utilization. The land would suffer—ultimately; the people would benefit, at least temporarily. Circumstances can force a people to pay an exorbitant price for soil protection.

The Dutch administration in Java has carefully preserved and encouraged native anti-erosion agriculture, and the same principles are applied to European-controlled estates. There are no social barriers between European and native in Java. The primary object of agriculture is to feed the people; the food supply of the community as a whole must be maintained on a permanent and secure basis before rubber, tobacco, coffee, etc. can be produced for export. One can speculate on the extent to which a colour bar might have washed the mountain soils of Java into the sea.

The newer countries are most seriously afflicted with erosion where their populations are thinnest because small populations are found where the water supply is scarce or erratic, and where the adopted agriculture of more humid regions is most inappropriate to the natural environment. The climatic conditions most conducive to erosion are those most inimical to dense settlement.

Nevertheless, denser settlement than is at present possible in semi-arid regions is perhaps the most certain prophylactic against continuing or recurrent erosion. The more men there are settled to the square mile, the greater is their potential mastery over the soil and—a more practical point—the more intensive is their agriculture. Semi-arid soils in the virgin state contain immense reserves of fertility which one man with a machine can exploit as well as twenty men without a machine. One man and his machine can extract from the soil enough food for twenty men, and nineteen-twentieths of the produce can be sold off the farm. The farmers of semi-arid lands have been the greatest exporters of soil fertility. They have gone on exporting it without putting anything back until in many places only the one-twentieth necessary to support the farmer has remained. But long before that happens the soil may lose its stability and the last five- or ten-twentieths of soil fertility vanish in a cloud of dust.

How is one to stop the wholesale plunder by the cities of the chemical fertility and physical structure which preserve these soils from wind and water erosion? The measure frequently recommended and already adopted in places is temporarily or permanently to retire the exhausted and 'sub-marginal' lands from cultivation and throw the burden of feeding the cities on to other areas. An alternative measure would be to bring the city

people on to the thirsty land, to consume there the food that they produce, and to enrich the soil with their labour and lives. An ideal that is not easily realizable, for though one can retire land from cultivation with a stroke of a legislator's pen, one cannot force or induce a multitude to settle in the desert, where it would be destined to die of thirst. The supply of water, of course, sets the limit to settlement in semi-arid land.

Similarly, shortage of water, for how many thousands of years we do not know, checked the development of embryonic civilization on the fringes of the Asiatic deserts. There must have been innumerable unrecorded attempts to cultivate the desert fringe by primitive dry-farming methods, but most attempts would be frustrated by the wind blowing away the cultivated soil and by the slow encroachment of the desert. Perhaps some dry-farming methods were successful enough to allow primitive, half-savage communities to hang on until in the course of ages they evolved the principles of irrigation engineering and produced the phenomenon of civilization. We can imagine the frequent retreats from the desert to the humid river bank and the final triumphant advance as the river was brought under control and its waters diverted at will over the fields.

We can now observe an analogous retreat from semi-arid to moister regions. On the whole, men can maintain the positions they have established in really arid country because the art of irrigation, acquired thousands of years ago, has not been forgotten. It is, however, still beyond human capacity to irrigate the vast, semi-arid continental plains which have become the granaries feeding the world's industries. The granaries are being destroyed because they have not enough water for the task they have been called upon to perform, and the only type of agriculture, except by irrigation, that mankind has mastered is suited to a humid forest environment. Industrial regions are being forced by a combination of political and economic circumstances to rely more upon their own agricultural resources, but the process of contraction which this involves cannot continue indefinitely. The semi-arid plains are the next field which an expanding civilization will conquer. To-day's retreat will be followed by a carefully planned attack when more experience of the adversary's tactics has been gained.

Fertile grassy plains occur in every continent. Civilized man has invaded them all, but they are not all destined to bear mature civilizations. At present the fickle fortunes of the battle favour Man in some and Nature in others. South America is in the advancing, pioneering stage. The cream of fertility is fast being extracted from the Argentine pampas, but erosion causes little concern except to the far-sighted. North America is in retreat after a phenomenally rapid advance, but is laying careful plans for a steady, though undramatic counter-attack. In the humiliation of defeat North America has learnt to respect the mettle of her adversary. Australia, isolated and thirsty, is also in retreat. South Africa is marking time, her unique racial difficulties bar retreat, and advance is impossible. Russia has formulated a stupendous plan for overcoming once and for all the social limitations imposed by insufficient rainfall on her fertile steppes.

The Russian plan is magnificent in conception, but it remains to be seen whether it can or will be carried out. It consists in bringing the principal rivers and water resources of the Soviet Union into one interlocking system under complete human control. By means of locks, barrages and canals it is proposed to link together the north-flowing and south-flowing river systems as well as the separate rivers in each system. Similarly the east-flowing and west-flowing systems of the Ural watershed are to be united. If water which is required to fertilize and populate the steppes, to be converted into power, to be utilized for navigation or to check the advancing desert is being wasted in the wilderness of the northern swamps, a turn of a key or the opening of a sluice will bring it to its proper place. Flood and drought will be disciplinary measures which Man, and not Nature, will exercise on those who do not toe the line.

When men are able to break down or circumvent the barriers which separate the wet from the dry lands, drought will lose its terrors and a limitless new field for human achievement will be opened up on the semi-arid plains.

The technical and administrative problems presented by such a scheme are immense. They were considered by a plenary meeting of the Academy of Sciences in 1933, since when very few details of progress have been available outside Russia. The

main scheme was to be completed in the fourth five-year plan, but if it were successful it would make little difference, in the perspective of history, whether it were finished after four or forty five-year plans. It would open a new chapter in human history which would not be closed for thousands of years.

The greatest obstacles to the accomplishment of this feat are not technical, but biological. The scientists assembled at Moscow took into account not only the water requirements of farms and farmers, of power stations, of industries and of navigation but also the effects of their controlled water régime on the level of the Caspian Sea, on the lives of fishes and on the distribution of insects. They appear to have overlooked (perhaps purposely) the incalculable effects on human ecology. Will the Utopia they have planned for crops, cattle, birds, fishes and insects as the servants of men be habitable by the masters—by the 'collective men' for whom it is all being done? We do not know what type of social organization befits an artificially watered community on a vast continental plain. It may be the modern Russian type, but more probably it will have to evolve slowly and painfully to an unknown maturity, and until it has evolved, the triumphs of the water engineer will remain hollow. The Russians have planned to complete outright the conquest of the semi-arid plains in the only way imaginable, short of making rain, but they have not accomplished it. Their powerful adversary may throw them back in disorder if they advance too rapidly. They have missed the salutary but harrowing experience of a fully fledged capitalism operating freely over their fertile steppes.

The Russian plan will not come to fruition this century; perhaps it will not even be attempted as a whole but only in isolated parts, like the Volga-Don canal. It is a dream which at some distant date may be realized when likewise the rivers and lakes of Northern Canada may contribute their quota of water to the parched fields of the Dust Bowl and the Congo and Zambesi bring new life to East and South Africa. Plenty of water falls on the earth, but it does not fall on the new and promising fields of human endeavour in sufficient quantities or at the right times to provide both the primary needs of civilization and a protective cover for the soil. The present civilization

has desiccated the forests; the next will moisten the grasslands. We can only guess how that triumph will ultimately be achieved.

The United States are also planning a stupendous attack on the prairies, but their immediate objective is less ambitious than Russia's. They plan to restore the Great Plains to stability—to a state of equilibrium in which men will be partners in, but not masters of, the natural economy. Mastership may come later, but it is useless to plan for that before the potential masters have learnt the duties of partnership. The brute skill of the engineer is invoked where the land has been torn by floods and gullies, but since the first shock of the retreat (which became a rout after 1929) from the Plains has passed, engineering has been relegated to the background of the plans for the renewed attack on a nation-wide front. The plans centre round the persuasion of a free people not to despoil their heritage for the sake of the present or in desperation at their plight.

Soil conservation began by the retirement of derelict lands from cultivation and the introduction on individual properties of the straightforward conservation measures that have already been described. Retirement of land at once produced the social problem of re-settlement, the adoption of conservation measures imposed additional financial burdens on the good farmer and placed him at an economic disadvantage to his less careful neighbour. Soil conservation on one farm was often wasted effort when the adjoining farms were left unprotected. It was seen that soil conservation required, firstly, the expenditure of labour on the land without regard to the financial return, and secondly, close and sometimes self-denying co-operation between individual landholders. In short, it required a complete reversal of the prairie farmer's outlook on life—an outlook which he had inherited from his forefathers and which they had acquired through centuries of close association with a humid environment. It was not sufficient to send teachers to explain the merits of terracing, strip-cropping, listing, etc. These measures do not make the Great Plains humid. It is difficult to change an ingrained human attitude to the land, but easier than to change the climate. 'The basic purposes of economic life do not change. The desire for security, stability, a rising standard of living, increased leisure, self-expression and creative work,

remains fairly constant. It is the ideas concerning ways and means by which these objectives may be achieved that must be subject to revision.'[1]

In *The Future of the Great Plains* are listed eleven attitudes of mind characteristic of the prairie settler that require modification. Some of them already seem irrational and out of date, nevertheless they have become firmly implanted in the settler as a consequence of the economic circumstances prevailing until a decade or two ago, and they are not so readily uprooted as they themselves have uprooted the settler. The attitudes of mind, indicating limitless optimism and the deceptive sense of power that comes from wealth too easily won, are: that Man conquers Nature; that natural resources are inexhaustible; that habitual practices are best; that what is good for the individual is good for everybody; that an owner may do with his property as he likes; that expanding markets will continue indefinitely; that free competition coordinates industry and agriculture; that land values will increase indefinitely; that tenancy is a stepping-stone to ownership; that a factory farm is generally desirable; and that the individual must make his own adjustments to calamity.

These attitudes of mind have determined the development of the prairies and brought them to their present condition. They are the natural attitudes to adopt towards an extremely productive, lifeless natural resource, as the soil was supposed to be. The fact that the soil is very much alive and reacts violently against any treatment which weakens its vitality makes all the difference to the attitude to be adopted towards it. The attitude adopted towards the prairie soils was essentially that which European farmers had correctly adopted towards humid forest soils, but modified in the wrong way by the greater ease with which virgin prairie soils can be exploited by modern methods.

Thus the basis of a comprehensive plan for rehabilitating the prairies must be mass-psychological. The mentality of the farming community must be adjusted in accordance with the nature of the soil, or more accurately, with the nature of the environment. (Note that the Russians, confronted with much the same problem, propose to tackle it by adjusting the environment to a

[1] *The Future of the Great Plains*, p. 63.

preconceived political State.) Once a suitable attitude to the land has been instilled into the community, the use of soil-conservation methods will become almost instinctive; without the right attitude the methods will be used under constraint or through fear, and a natural, lasting stability will not be achieved.

Nobody knows what the right attitude should be. The plan of counter-attack on the recently victorious aridity of the Great Plains consists in experimenting with numerous social and economic measures, holding on to the advantage gained if the experiments show signs of succeeding, and retreating when they fail. Groping in the dark against a powerful adversary who has to be accommodated rather than conquered, democracy, which can admit defeat, is better placed than a dictatorship would be. The first Agricultural Adjustment Act misfired and the Administration retreated to renew its economic attack on soil erosion with a weapon of different calibre. Perhaps it attempted too much in coercing industry to assist an unorganized agriculture to put its house in order.

The reconstruction of rural life so that not a drop of water (the shortage of which alone holds back the advance on the prairies) is wasted, is the real basis of soil-conservation planning in the Great Plains. America does not and cannot plan, except on an infinitesimal scale, to increase the water supply by new irrigation works, but much can be done to increase the utility of the available water during its passage over and through the earth. 'Hundred-per-cent efficiency' of water utilization is the unattainable ideal, but a very much higher efficiency can be achieved than has been in the past.

By regarding the optimum utilization of available water as the key to soil conservation in the Great Plains, the matter becomes one involving the entire population, since unless everybody gets his fair share of water the social machine is liable to break down. If farmers get more than their share and utilize it wastefully, civic supplies, irrigation works, power stations and navigation may go short. The first aim of planning is to ensure that crops have enough water to produce good harvests, as far as possible adjusting cropping practices with a view to maximum water economy. Then all water not absorbed and trans-

pired by crops must be protected from waste. A considerable proportion of the surplus water is bound to be wasted by evaporation and little can be done to reduce this loss. The greatest source of waste that can be controlled is run-off. Apart from the fact that run-off water is usually required for crop growth, any subsequent value it might have in rivers and reservoirs is largely negatived by the load of eroded soil which it carries. Run-off water robs the farmer of water and soil and disfigures his land with gullies. It permanently reduces the effectiveness of the rainfall by removing the absorbent topsoil, it silts up rivers and reservoirs, increases the flood hazard, destroys fish spawning grounds and upsets the natural balance of wild life. Prevention of excessive run-off and its inevitable concomitant soil erosion is therefore by all counts the most important first step in reviving the farms and cities of the Great Plains. It has been estimated that up to 50 per cent of the total rainfall is lost in run-off; the proportion is lower on well farmed land, but much higher where serious erosion has occurred.

A reduction of run-off will not by itself restore the Great Plains to their position as one of the naturally most productive areas in the world, but until run-off has been permanently stabilized at a low percentage of the total rainfall it would be fruitless to consider further possibilities of social and economic development. The effective, as distinct from the total, rainfall limits both the population capacity of the region and the economic activity of its people. And while erosion continues the effective rainfall decreases. It has been estimated that not less than 165,000 people have moved from the Great Plains since 1930.

Reduction of run-off would be a simple matter were human beings automata, but since (in America at any rate) they are not, the matter becomes very complicated. It involves the intricate question of individual rights to water that must serve the whole community from the time it falls on to the ground until it reaches the ocean. The organization of irrigation communities, based on water rights, was simple in comparison since the supply and distribution of water could be very largely controlled by a central authority. Farming under irrigation is the most independent of, and farming under semi-arid conditions the most dependent upon, the vagaries of weather.

When a farmer protects his land against erosion, he usually derives almost immediate benefit in the form of better harvests and a greater sense of security, although these benefits do not necessarily compensate him financially for the costs of protection. His neighbours may benefit not only through the cessation of soil washing or drifting from the protected farm but also, less obviously, through the surplus water percolating through the soil and being stored for common use in the underground reservoirs which feed wells and springs. The careful farmer thus has a case for claiming that his neighbours should bear part of the cost of conserving his soil. At the same time, if the neighbours neglect their land, the careful farmer's good works may be utterly wasted; he should therefore be able to insist that his neighbours take adequate measures to conserve their own soils and should be prepared to pay his share, proportionate to the indirect benefits he receives, towards the cost of protecting the region from excessive run-off and erosion.

Regional co-operation against erosion is thus not only highly desirable as offering a united front against the common enemy, but also quite acceptable to the individualist farmer whose philosophy is that a man pays for what he gets, and gets for what he pays. Co-operative action among landholders has been mainly a natural growth nurtured on the realization that something decisive had to be done quickly, and that the co-operator got, on the whole, a fairer deal than if he stood by and for himself. One of the most hopeful and significant developments in co-operation is the growth of 'soil-conservation districts' which may become miniature States within States. Co-operative grazing associations, permitting their members to graze their cattle under control on common pastures, so that an entire range may not be destroyed by overgrazing on its most valuable parts, are also increasing in number. Montana has established by statute a State Grazing Commission with authority to supervise the operations of co-operative grazing associations. North and South Dakota have passed analogous statutes.

Federal and State authorities are enforcing safe land utilization for the common welfare on areas under their direct control, and are extending their control by acquiring sub-marginal or exhausted land and danger spots. The Taylor Grazing Act was

designed to achieve these objects on the public domain; States are encouraged to pass 'rural-zoning' Acts, enabling counties or districts to be reserved for special purposes such as forestry, grazing or recreation. The whole trend of evolution on the Great Plains is towards the elimination of the individual in favour of the commune. The independent capitalist farmer is undergoing gradual self-liquidation as certainly as, though less drastically than, the Russian kulak was liquidated in the years following the revolution.

This trend towards a corporate society in the Great Plains has only been apparent for a short time; it would be rash to speculate on the destiny to which it will ultimately lead the people. It has been a natural reaction to the continued destruction of the land and it is operating to reduce surface run-off and erosion and to increase the effective rainfall. A time will come (probably not before setbacks and disappointments have been endured) when the effective rainfall can be increased no more by human science and collaboration, when the Plains will have been restored to their former productivity and will be capable of supporting a considerably larger population than hitherto. But it is unbelievable that that stage should mark the end of their progress for all time. There is plenty of waste water in North America. What we are now observing is merely the first stage of weaving the disjointed strands of American individualism into a definite pattern harmonizing with the semi-arid environment of the Plains.

We may perhaps forecast one future stage in the evolution of the social structure that is rising out of the impulse to make better use of the rainfall. When the rural soil-conservation districts, co-operative associations and the rest have become more firmly established and politically more powerful, they will be in a position to point out to urban communities the advantages the latter derive from a safer and more ample water supply, and to claim as a right the material co-operation of the cities in restoring the countryside. The interdependence of town and country will become something close and real. At present the much talked-of economic interdependence of town and country is, to say the least, somewhat vague; certainly the prosperity or otherwise of a single industrial town need have little effect on condi-

tions in the surrounding country. But when the bond between town and country is recognized to be formed not by the indirect interchange of produce but by mutual co-operation to obtain the greatest use from a limited water supply, the country, upon the utilization of which the dependability of the water supply largely rests, will have the ruling voice in determining its relationships to the towns. It has frequently been pointed out that the weakness of the country's present position is economic—that industry is now organized to maintain prices by varying the volume of production to the current demand, whereas agriculture cannot artificially control prices to the same extent and can only meet a falling demand and falling prices by increasing production, often with disastrous effects both on the farmers and their land. Urban prosperity, indeed, may actually be bought at the price of rural distress.

When, however, society has to go back to the beginning and build itself up on a new basis, when the struggle for existence ceases to be primarily a struggle for markets and becomes a struggle for water, the power of the country in relation to that of the towns will increase. The men who rule the rivers according to the way they manage the land, will rule the nation. They may not have the wealth, but collectively they will have the power now in the hands of the captains of industry. Industry will become the handmaid of a balanced and fruitful agriculture upon whose enduring prosperity the fate of the towns will depend.

Thus the foundations of a new, semi-arid civilization will be built on solid earth. The average level of bank balances may not be as high as has been anticipated for the time when the Plains shall have been restored to stability, since it will no longer be possible to cash soil fertility at will. In the exploitative era, however, money was too easily obtained from the soil. Building foundations is hard work and there is very little to show for it immediately afterwards. Hence the job is not undertaken and carried through except under compulsion from some grave and persistent adversity such as soil erosion.

We have dealt at some length with the prospects of the great plains of America and Russia as far as these can be judged from the measures now being taken or contemplated to make wind and water the servants instead of the enemies of civilized man.

The plains seem destined to nurture the next civilization if they can survive the pains of travail which they are now suffering. Unless the Argentine becomes an unexpected aspirant for the honours, the race for supremacy on the plains will be run between North America and Russia, America paradoxically assuming for the time being the role of the tortoise and Russia that of the hare. No imaginable human ingenuity can bring the water of more humid lands to Australia. She can advance to the limit imposed by the most efficient utilization of her scanty rainfall and rivers, but she can go no further. South Africa's advance will be checked by the inertia and low intellectual capacity of the great mass of her people as well as by the natural poverty of her soils.

We can foresee no great future for civilization in the tropics. The main energies of the white races will be fully occupied in preserving, if possible, their dominant position on temperate, humid soils and in building new empires on the great continental plains. Soil erosion can be prevented by adapting to tropical agriculture the mechanical and cultural methods which are proving successful in temperate lands, but the highly developed co-operative organization and social interdependence which are part and parcel of soil conservation cannot be achieved in the tropics except, perhaps, in countries like Java where the natives have reached a relatively advanced stage in social evolution. We have argued in Chapter XX that soil erosion in tropical Africa presages what must, from the European standpoint, be regarded as a reversion to a period of feudalism. In a feudal society in which the land was controlled by a dominant minority and worked by a subject majority, tropical soils could be safely cultivated and their fertility maintained in the interests and service of a more advanced civilization. Not until a race of men is born that can not only live and multiply in humid heat, but can also perform with labour and intelligence the complex biological functions of the indigenous vegetation, will the tropics be anything more than a luxury or a liability to their colonial rulers.

Finally, let us contemplate the prospects for Western Europe, which can still claim to be the centre of modern civilization, but has hardly suffered at all from the destruction of its soils—that otherwise almost universal disease of civilization. The area that

has escaped erosion represents a distinct ecological region of humid deciduous forest whose soils were, originally, not naturally suited to growing the grain crops upon which civilization depends. The conversion of the humid forest environment to a less humid agricultural environment in which wheat could compete successfully with the indigenous flora was a tremendous achievement. Except in the more arid Mediterranean with its dry summers, deforestation was not accompanied by severe, accelerated erosion, partly because of the well-distributed, gentle rainfall, partly because the process was so gradual that soil changes could keep pace with vegetation changes. Localized erosion has occurred on mountain slopes, in France and Switzerland for example, where extensive deforestation has been done for lumbering rather than for agriculture, and definite evidence of former erosion can be seen on the now grass-clad hills of Wales.

The conversion of the European forest lands to their present condition of immense agricultural productivity has taken at least a thousand years to complete. Little technical progress in agriculture took place in the early stages of the conversion while the soil would have been particularly liable to deteriorate under flagrant exploitation. During the Dark and Middle Ages, the soils were not subjected to any abnormal strain and evolved into an agricultural type almost as naturally as though agricultural crops had somehow supplanted the trees without human intervention. When, after centuries of adolescence, European civilization blossomed out in the nineteenth century, the countries of the New World were called upon to feed the flower. The enormous increase in Europe's population was accomplished without disturbing the established equilibrium between humanity and the soil although, as we have seen, it has very clearly prevented equilibria from being established elsewhere. Europe did not need to strain the productive capacity of her soils until the World War; new fertilizers enabled the soils to produce without difficulty enough to make good any year-to-year deficiencies from overseas.

The War displayed the full potentialities of European soils. Within four years the overcrowded warring nations became almost self-sufficient in food. It was not a comfortable nor a

lasting self-sufficiency but then the main energies of the nations were not directed towards food production. Since the War economic circumstances have compelled them, one after another, to perpetuate policies of self-sufficiency and thereby to give a great impetus to the growing movement of soil conservation in the rest of the world. For diverse reasons the surpluses producible in the thinly populated countries will not again be freely available to Europe. Whether for her ultimate good or not, Europe will have to rely to a far greater extent than hitherto on her own soils to feed her teeming populations. For the first time since they came under cultivation the soils will be subjected to a serious strain.

We cannot even guess whether or for how long the soils will be able to stand the strain. A comparable situation has never arisen before. Our knowledge of how certain soils react to certain external circumstances is derived from a few years' observation only, and is totally inadequate to help us here. It may, however, be regarded as highly improbable that the soils of Western Europe, if they should become exhausted by prolonged, intensive cultivation, will ever suffer the catastrophic erosion that has overtaken the exploited prairies or the cut-over forest soils of Eastern America. They will inevitably grow old, but they will not die. A gradual deterioration of soil structure, imperceptible perhaps within a single generation, will be the most probable manifestation of the strain on the soils. Something—but not enough—is being done in most countries to counteract the cumulative ill effects on soil structure of a falling humus supply, increasing acidity, and the single-minded enthusiasm of all people for the outward insignia of a healthy countryside—high yields. More could be done if the principal aim of agricultural policy were to preserve soil structure for the next century even at the cost of curtailing production and weakening the first line of 'national defence'. Were another war to come, ploughs would tear up the structure-forming meadows and pastures, humus-providing animals would be slaughtered, soil improvement would be neglected, the vital reserve of soil fertility would be mercilessly broached. Unlike America, Europe cannot adopt a long-term soil-conservation policy in which the eventuality of war is a secondary consideration. Europe must build for the

immediate future which has little significance in the eternal process of soil evolution.

A deterioration of the soil structure slowly built up during the past centuries would produce conditions favouring a less exacting flora than agricultural crops. Such conditions would not necessarily terminate Man's dominance over the soil. A highly industrialized civilization does not live by bread alone. To an ever-increasing extent it needs wood—for newspapers and books, for clothing, for fuel, for explosives, for paints and varnishes and for a hundred other things. A time may come when self-sufficiency in wood is more urgent than in wheat, when civilized Europe will welcome and encourage the irresistible return of the forest on to agricultural land. The mild, maritime climate of Western Europe is a guarantee that the soils will not erode away as a result of any conceivable mismanagement. Our civilization will be spared the fate that overtook its predecessors but in the end the forests will claim back their dominions as the deserts of the East have claimed back theirs.

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